CONTRIBUTIONS TO PRE-CAMBRIAN GEOLOGY

GEOLOGY OF LIMESTONE MOUNTAIN

MICHIGAN GEOLOGICAL AND BIOLOGICAL SURVEY.

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CONTRIBUTIONS TO THE PRE-CAMBRIAN GEOLOGY OF NORTHERN MICHIGAN AND WISCONSIN.

R. C. ALLEN AND L. P. BARRETT.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN.

E. C. CASE AND W. I. ROBINSON.

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LETTER OF TRANSMITTAL.

To the Honorable, The Board of Geological and Biological Survey of the State of Michigan:

Gov. Woodbridge N. Ferris.
Hon. Fred L. Keeler.
Hon. Wm. J. McKone.

Gentlemen:—I have the honor to transmit herewith two manuscripts, viz., Contributions to the Pre-Cambrian Geology of Northern Michigan and Wisconsin, by R. C. Allen and L. P. Barrett, and The Geology of Limestone Mountain and Sherman Hill in Houghton County, Michigan, by E. C. Case and W. I. Robinson, with the recommendation that they be printed and bound as Publication 18, Geological Series 15.

Very respectfully,
R. C. ALLEN,
Director.

Lansing, Michigan,
June 16, 1915.

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CONTRIBUTIONS TO THE PRE-CAMBRIAN GEOLOGY OF NORTHERN MICHIGAN AND WISCONSIN.

R. C. ALLEN AND L. P. BARRETT.

CHAPTER I.

INTRODUCTION AND ACKNOWLEDGMENTS.

R. C. ALLEN.

In 1909 the writer became interested through, studies in the Iron River district, in the problems of the pre-Cambrian terranes which occupy the great area west of the Crystal Falls and Iron River districts and south of the Marquette and Gogebic iron ranges to the state boundary line and beyond into Wisconsin. This region is a great Huronian interior into which the better known and structurally distinct "ranges" on its north and east borders coalesce and lose their identity. It is unattractive to the geologist because of the general scarcity of rock exposures, its apparent lack of structural individuality, its unimportance from the mining standpoint and the difficulty of access to many of its parts. Notwithstanding all of these it has seemed to the writer that a serious attempt should be made to acquire what information there is to be had of the geology of this region in order to reduce this geological "no man's land" to terms of general description even if nothing further could be expected to be accomplished. Although the conditions to be faced were discouraging, the labor great, and the results certain to be disproportionate to the cost in time and money in comparison with equal expenditures in more favored regions, it was finally determined to embrace the task of making a field examination of the entire area so far as it lies within the state of Michigan. Field work was prosecuted during the summers of 1910, 1911, 1912, and 1914. Fortunately for the progress of geologic knowledge of this district, a number of individuals became interested in 1911 in exploration for iron ore in northern Wisconsin adjacent to the Michigan boundary and a syndicate was formed under the direction of Dr. F. I. Carpenter to finance the geologic examination and reconnaisance exploration by drilling of a large territory extending westward from the vicinity of Lake Vieux Desert to near Butternut, Wisconsin, a distance of about 65 miles. The supervision of the geologic work, which fell to the writer, has enabled him to combine in this volume the results of private enterprise in Wisconsin with the work of the Michigan Geological Survey in Michigan.

The area which has been examined in the field contains not less than

2,000 square miles including 42 townships in Michigan and 32 townships in Wisconsin. (See Fig. 1.) Nearly all of the townships on the Michigan side were examined in the 80's by the Michigan Geological Survey but the information thus aquired was never used to any practical extent, if indeed it was understood. With the exception of the admirable notes of Prof. A. E. Seaman on certain townships none of this early work has been of much value in the present investigations beyond a saving in time in search of some of the exposures and in mapping parts of a few of the magnetic belts. These magnetic belts heretofore have not appeared on geologic maps but parts of some of them, more or less correctly located, appeared 20 to 30 years ago on commercial maps issued by land holding companies

A large area of Huronian rocks extending south of the Marquette iron range to about the line between townships 46 and 47 North, west to the Eastern sandstone and northeast in a great tongue fringing the Archean mass north of the Marquette district remains to be examined. It is planned to continue the work in this region in this and subsequent years.

In many townships in Wisconsin and in a number of those in Michigan rock outcrops are entirely wanting. The drift covered townships, and in fact the entire area, has been magnetically surveyed by the use of the dip compass and most of the magnetic belts thus located have been explored to some extent by diamond drilling, but the geology of the non-magnetic drift covered territory still remains and doubtless will remain for many years the subject of speculation and inference.

The geology of the area between the Gogebic and Iron River districts in Michigan and southward into Wisconsin is treated in the following chapters as a composite of several areas. Each of these has a well defined geologic individualism but is separated from adjacent ones by tracts in which this individualism is lost, through partial or complete lack of geologic data and disappearance of identifiable structures and stratigraphic horizons. Stated in clearer manner perhaps, there are (1) some areas in this composite in which the geologic data, while not so complete as to afford an entirely satisfactory view, are relatively ample, (2) some areas respecting which freedom of inference from meager facts alone renders possible any connected ideas of the geology, however hypothetical, and (3) some areas of which such ideas as may be advanced must rest solely upon inference.

For purposes of description it is necessary to consider these several areas separately. The discussion of each unit or separate area should, however, be approached with an understanding of its relations to adjacent areas and to those factors in the geology which have a general application to the entire region.

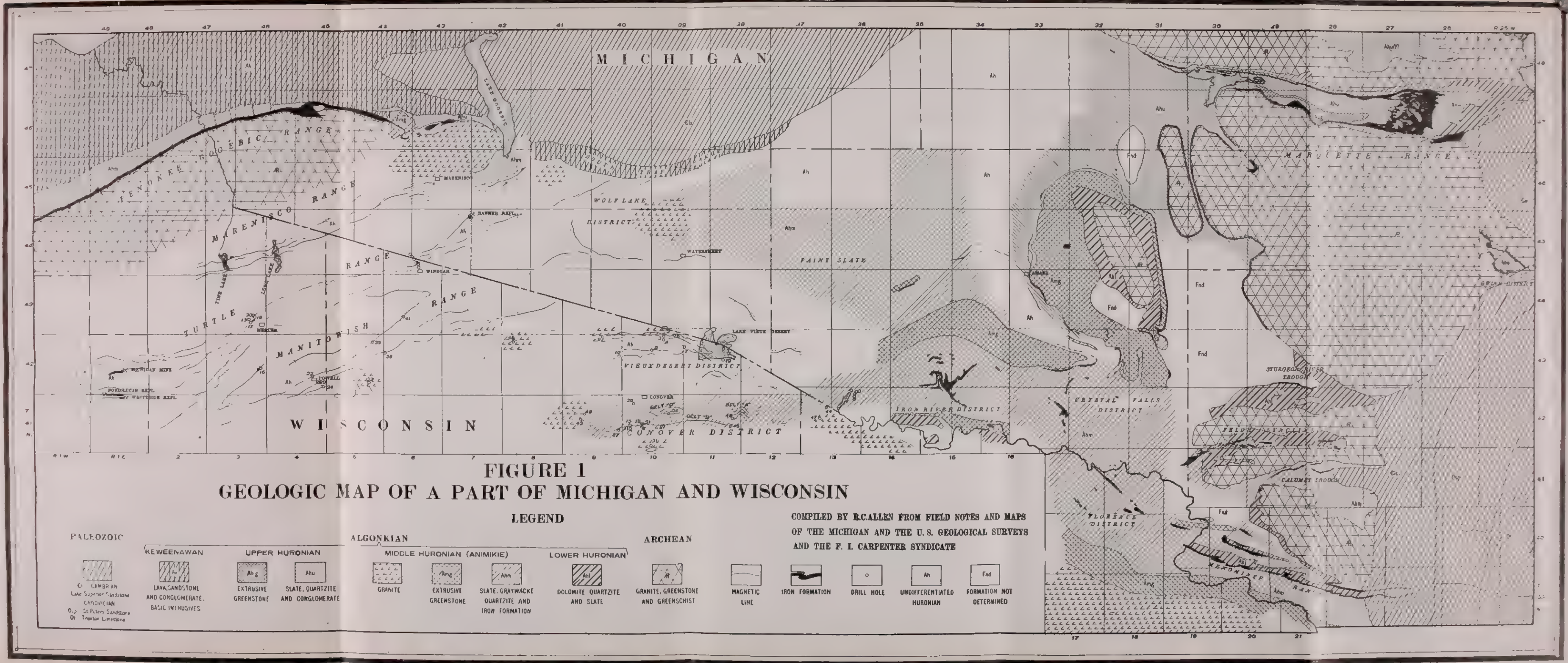


FIGURE 1
GEOLOGIC MAP OF A PART OF MICHIGAN AND WISCONSIN

COMPILED BY R. C. ALLEN FROM FIELD NOTES AND MAPS OF THE MICHIGAN AND THE U. S. GEOLOGICAL SURVEYS AND THE F. L. CARPENTER SYNDICATE

Let us refer for a moment to some earlier conceptions of the geology of this region. On early general geologic maps a line was drawn from the south end of Lake Gogebic southeasterly to the headwaters of the Brule river, separating the Algonkian rocks northeast of it from the supposedly Archean rocks to the southwest, forming what was then thought to be a part of the great Archean "Isle of Wisconsin." To this conception may be traced the idea, which was prevalent among explorers for iron ore as recently as 1909, that the Huronian series swing from the Iron River district northwesterly parallel to this hypothetical line and connect more or less directly with the Huronian of the Gogebic range. In 1911 Van Hise and Leith shifted this hypothetical line in general westward** and introduced an area of Archean "green schists and iron bearing formations" several miles broad extending from the south end of Gogebic lake eastward some 20 miles, bounded on the north by the South (Keweenawan) Trap Range and on the south by a narrow belt of Laurentian granite. The territory to the southwest was mapped as "undifferentiated pre-Cambrian." This classification of the rocks south and east of Gogebic Lake has not survived recent studies but the general mapping makes an advance over earlier attempts because it expresses doubt concerning the Archean age of all of the rocks included in the "undifferentiated pre-Cambrian," formerly mapped as Archean.

The assignment of an igneous complex or metamorphic schist series to the Archean in the absence of definite evidence of later age may be permissible for purposes of general mapping if qualified by an appropriate expression of doubt concerning its correlation. It sometimes happens that a correlation which was sufficiently qualified by the author as regards the points of doubt and uncertainty, through long standing and repetition in text books and other geological literature, becomes fixed in the minds of later workers as *fact* in distinction from *inference*, and to this extent acts as a bar to inquiry which otherwise would be directed toward a final solution of the uncertainties. So far as concerns the region under examination we are unable to say that rocks *older* than Huronian are present. On the other hand there is indisputable evidence that *most* of the area heretofore mapped as Archean and undifferentiated pre-Cambrian is in reality Huronian. The *granite* which has been considered as underlying most of the supposedly Archean area is intrusive into the Lower and Middle Huronian (Animikie) sediments. It constitutes a great batholith which seems to occupy many thousands of square miles in northern Wisconsin and is represented by outlying bosses in the east end of the Gogebic

**See "Geologic Map of the Lake Superior Region, with Sections," accompanying Monograph No. 52, U. S. Geological Survey, 1911.

range and southward and eastward in Michigan. There is clear evidence that this granite has displaced large masses of pre-Cambrian sediments. Nearly all of the sediments which remain have been rendered schistose, gneissose and thoroughly crystalline and in many areas they have lost all evidence of sedimentary origin. The profound exomorphic effect of granitic intrusion is apparent, particularly in the Manitowish range, in the Vieux Desert-Conover district and in the vicinity of the Wolf Lake granite north of Watersmeet. While there are other intrusives *it is apparent that this enormous intrusive granite mass when considered with its profound metamorphic effects on the pre-Cambrian sedimentaries is the great, significant, outstanding feature of the geology of this region.*

The region may be described in the most general terms as a series of highly folded belts of Huronian sedimentary rocks and, in some districts, associated contemporaneous igneous effusives, showing marked parallelism to the axis of the great Lake Superior geosyncline, and which are invaded, here and there terminated or interrupted, and in great part separated, one from another, by intrusive granite and schists of doubtful origin. The character of the folding is such as to support the inference that the Archean rocks were exposed by erosion on the anticlinal areas prior to the granitic intrusion of late Middle Huronian (Animikie) time and inasmuch as the sedimentary rocks were not entirely replaced or absorbed by the invading granite it must be presumed that the Archean also still remains in some of the territory not occupied by the sediments. That it has not been identified with certainty must be laid to total lack of exposures of contacts between the sediments of the Huronian group and the older terranes on which they were deposited, as well as a general scarcity of outcrops, and the fact that drilling and other exploratory operations have been confined to the vicinities of exposures of the sedimentaries and, in drift covered areas, the magnetic belts by which the positions of the sedimentary rocks are to considerable extent marked.

The geologic field investigations which are discussed in following chapters together with the data which has become available through exploratory drilling and underground mining have thrown much added light on the problems of correlation of the Huronian group and have furnished a body of evidence which, in our opinion, may be interpreted satisfactorily only through a revision of the present correlation of this group throughout the Lake Superior region in the United States. The following chapter is a discussion of this evidence and a revision of the correlation in the direction of a clearer and more adequate interpretation of present information. This chapter precedes the discussion of the various districts because it serves as an introduction to the general theme and explains the correlations which have been applied throughout to the Huronian group in Michigan.

This volume is presented to the public under a full appreciation of its inadequacies. These, however, do not express lack of diligence on the part of the writer but rather the measure to which he has been able to surmount the difficulties imposed on him by the meagerness of the geologic data afforded by an exhaustion of available sources and present means. While he assumes full responsibility for the shortcomings of this presentation he desires to express his indebtedness to his assistants and to share with them any merit which it may possess. Messrs. R. E. Hore, R. W. Clark, R. E. Ascham, R. A. Smith, Geo. B. Corless, L. J. Youngs, and L. P. Barrett, geologists, have rendered valuable service in the Michigan field, Messrs. P. G. McKenna, H. J. Allen, L. P. Barrett, W. I. Robinson, J. P. Goldsberry, and Geo. B. Corliss, in Wisconsin. I am especially indebted to Messrs. McKenna and Allen who have had joint charge of both field work and drilling operations in Wisconsin, to Mr. R. W. Clark for petrographic descriptions of thin sections of the Paint slate series, and above all to Mr. L. P. Barrett who executed the field mapping of the eastern Gogebic range, made the greater part of the microscopic examinations of thin sections of the rocks in both Michigan and Wisconsin, and collaborated in the preparation of manuscript and illustrations. My indebtedness to Mr. Barrett is expressed in joint authorship of the chapters on the eastern Gogebic, Marenisco, Turtle, and Manitowish ranges, the Paint slate series and the Conover-Vieux Desert district. Thanks are due to the F. I. Carpenter syndicate for placing at our disposal all of its information relative to the geology of the area adjacent to Michigan in Northern Wisconsin without which it would be impossible to discuss the geology of that region and which has thrown much additional light on the geology of the contiguous area in Michigan.

For their bearing on the general subject of Huronian correlations I have introduced a description of the Gwinn and Little Lake areas in Marquette county and the east end of the Menominee range. The article by Dr. E. C. Case and W. I. Robinson on the geology of Limestone Mountain and vicinity has no bearing on the main theme of this volume but is appended, with apologies to the authors, for want of a better present means of publication.

Lansing, Michigan.
June 17, 1915.

CHAPTER II.

A REVISION OF THE CORRELATIONS OF THE HURONIAN GROUP OF MICHIGAN AND THE LAKE SUPERIOR REGION.

R. C. ALLEN.

The Huronian group comprises at least three unconformable series of pre-Cambrian sedimentary and associated igneous rocks separated from the younger Keweenawan series by a great unconformity and from the older Archean system by another more profound unconformity. The position of the group has been defined by the Uniied States Geological Survey and by a committee of Canadian and United States geologists* (1904) as follows:

Paleozoic			Unconformity.
	Keweenawan		
			Unconformity
		Upper	
			Unconformity
Algonkian	Huronian	Middle	
			Unconformity
		Lower	
			Unconformity
	Keewatin		
Archean			Eruptive contact
	Laurentian		

Former correlations of the Huronian group as well as the entire pre-Cambrian of the various districts of the Lake Superior region in the United States are mainly the results of detailed field study and mapping by the United States Geological Survey. These studies have been published in a series of monographs on the most important districts and a final summary covering the entire region.**

*Jour. Geol. Vol 13, 1905, pp 89-104.

**The Penokee iron bearing series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise, Mono 19, U. S. G. S., 1892.

The Marquette iron bearing series of Michigan, by C. R. Van Hise and W. S. Bayley, with a chapter on the Republic trough, by H. L. Smyth. Mono 28, U. S. G. S., 1896

The Crystal Falls iron bearing district of Michigan, by C. R. Van Hise, J. M. Clements, W. S. Bayley, and H. L. Smyth. Mono 36, U. S. G. S., 1899

The Mesaba iron bearing district of Minnesota, by C. K. Leith. Mono. 43, U. S. G. S., 1903.

The Vermilion iron bearing district of Minnesota, by J. M. Clements, Mono. 45, U. S. G. S., 1903

The Menominee iron bearing district of Michigan, by W. S. Bayley, Mono 46, U. S. G. S. 1904

Geology of the Lake Superior region, by C. R. Van Hise and C. K. Leith, Mono 52, U. S. G. S., 1911.

In 1892 Irving and Van Hise published their completed work on the Gogebic iron range. They believed that the Huronian group in the Gogebic district comprises *two* unconformable series, the *Upper* and the *Lower* Huronian, and that the Upper Huronian or iron bearing series is probably equivalent to the Animikie of the north shore of Lake Superior. In 1896 Van Hise, Bayley and Smyth issued a monograph on the Marquette iron range. There were found here *two* unconformable Huronian series, the *Upper* and the *Lower* Huronian, which were correlated with the *Upper* and the *Lower* Huronian of the Gogebic range, the Negaunee iron-bearing series of the Marquette range falling in the *Lower* Huronian. This is the *dual classification* which was gradually extended to cover all of the other districts of the Lake Superior region until A. E. Seaman discovered about 1902 that the "lower" Huronian of the Marquette range is divisible by a great unconformity at the base of the Ajibik quartzite. In 1904 Seaman's discovery was formally recognized by an international committee of Canadian and United States geologists which adopted the tripartite classification of the Huronian group. The Negaunee iron-bearing series was separated from the Lower Huronian to form the new Middle Huronian but the old correlations outside the Marquette range were preserved. Nine years later (1913) Allen accounted for a tripartite division of the Huronian in the Gwinn synclinorium south of the Marquette range and correlated the Gwinn iron-bearing series with the Negaunee iron-bearing series of the Marquette district*. In 1914 Allen and Barrett found that the Upper Huronian as described by Van Hise and Irving on the east end of the Gogebic range includes *two* unconformable series. This discovery, in their opinion, has finally opened the way for a revision of the correlation of the Huronian group of the Lake Superior region on the tripartite basis in which most of the difficulties and inconsistencies in the old dual classification largely disappear.

The new correlations place the Animikie series in the Middle Huronian, rather than in the Upper Huronian as in former correlations. Briefly stated, the steps in the argument are these:

(1). The Animikie (iron-bearing) series of the Gogebic range is the equivalent of the Negaunee (iron-bearing) series which constitutes the Middle Huronian of the Marquette range; therefore, the Animikie series of the other Michigan districts, Minnesota and the north shore of Lake Superior is also the equivalent of the Negaunee series, i. e., Middle Huronian.

(2). The Negaunee series of the Marquette range is unconformably overlain by the Upper Huronian. The Ironwood (Animikie) series of the Gogebic range is also overlain unconformably by a series which is

*Jour. Geol., Vol. XXII, No. 6, 1914.

unconformably beneath the Keweenawan. This series is equivalent to the Upper Huronian of the Marquette range. Therefore the Animikie series is Middle Huronian.

CORRELATION OF THE ANIMIKIE SERIES AS MIDDLE HURONIAN.

Correlation of the Ironwood series with the Negaunee series: The Ironwood (Animikie) iron-bearing series of the Gogebic range is correlated with the Negaunee (Middle Huronian) iron-bearing series of the Marquette range because (1) these series occupy identical positions in the Huronian succession of these districts, (2) are essentially similar, (3) are underlain and overlain by essentially similar series, (4) are in practically adjacent territory, (5) there is substantial evidence of their equivalence through direct connection of the Negaunee series with the Vulcan (iron-bearing) series of the Crystal Falls-Iron River district which bears the same relation to a great granite batholith and its outliers as does the Ironwood series of the Gogebic range and its correlatives in the Marenisco and Turtle ranges, and (6) there is no direct *evidence* in favor of any other correlation.

The similarity of the successions in the Gogebic and Marquette districts is striking and coupled with proximity would ordinarily determine a direct correlation of the similar series occupying identical positions in the group even were there no further evidence of identity.

CORRELATION OF THE HURONIAN GROUP IN THE GOGEBIC AND MARQUETTE DISTRICTS.

	Marquette District.	Gogebic District.
	Greenstone intrusives and extrusives.	
	Clarksburg volcanics partly replacing Michigamme slate.	Graywacke and slate.
Upper Huronian	Michigamme slate carrying iron-bearing lenses (Bijiki schist).	Ferruginous and cherty slates and jasper.
	Goodrich conglomerate-quartzite.	Conglomerate.
	unconformity	unconformity
		Presque Isle granite.
	(Deep erosion)	Tyler slate.
Middle Huronian. (Animikie)	Negaunee (iron-bearing) formation and extrusive greenstone.	Ironwood (iron-bearing) formation and extrusive greenstone.
	Siamo slate.	Palms quartzite and quartz slate.
	Ajibik quartzite.	

	—unconformity—	—unconformity—
Lower	Wewe slate.	(Deep erosion)
Huronian.	Kona dolomite.	Bad River dolomite.
	Mesnard quartzite.	Sunday quartzite.
	—unconformity—	—unconformity—
Archean		

The absence of slate above the Bad River dolomite should be considered with the evidence of deep erosion in middle-lower Huronian time in the Gogebic district which not only removed the slate if it was ever present there but also the entire Lower Huronian over the greater part of the range. In respect to the Middle Huronian (Animikie) of these districts the situation is reversed, i. e. the thick Tyler slate formation above the Ironwood series is to be considered with the evidence of deep erosion of the Negaunee series and the development of iron ores on the exposed surface of the iron formation (now represented by the hard ores of the upper part of the Negaunne formation) prior to the deposition of the Upper Huronian. If the correlative of the Tyler slate was ever deposited on the Negaunee formation it had been removed prior to the deposition of the Goodrich quartzite. The Middle Huronian (Animikie) of both districts is characterized by volcanic activity which continued on into and culminated in the Upper Huronian in the Marquette range but apparently terminated prior to the deposition of the Copps formation in the Gogebic range.

There is a strong resemblance of the Copps formation of the Gogebic to the Upper Huronian of the Marquette range in respect to lithology and order of succession. At the base of these series is a great conglomerate which is overlain by slate and graywacke. Neither series carries a great productive iron bearing member but both contain jasper and ferruginous beds near the base, which in the Marquette district are locally iron ore bearing.

It can not be easily doubted that if Van Hise and Irving had disovered in 1892 the great unconformity at the base of the Copps formation on the Gogebic range and Van Hise, Bayley and Smyth in 1896 the great unconformity at the base of the Ajibik quartzite on the Marquette range, the correlation of the Huronian group of the Lake Superior region would have been *tripartite* from the beginning and not *dual* for the correlations have been built up on these two type districts which were earliest studied by the U. S. Geological Survey. The Ironwood (middle) series would *then* have been correlated with the Negaunee (middle) series because, as above stated, they occupy identical positions in the Huronian succession, are essentially similar, are overlain and underlain by essentially similar series, and are in practically adjacent territory. The character of the reasoning which was employed in separating the Negaunee and Ironwood series in the correlations would have united them had present information been available. There could *then* have been little, if any, reason for assigning these two iron bearing series to different positions in the Huronian group; certainly there is no reason for such assignment today particularly as there is additional substantial evidence for the correlation of the Ironwood and the Negaunee series which will be discussed below.

CORRELATION OF THE VULCAN (IRON BEARING) SERIES WITH THE NEGAUNEE (IRON BEARING) SERIES.

Marquette and Crystal Falls Districts: The basis of correlation of the formations of the Marquette and Crystal Falls districts is afforded by an indicated actual continuity of the Negaunee and Vulcan iron bearing formations. In 1903 H. L. Smyth traced the Negaunee iron formation from the Republic trough southwest around two major anticlines to the northeast side of the great oval anticline in the northern part of the Crystal Falls district*. The relation of the Negaunee formation in this area to a persistent magnetic line may be seen on Fig. 1. From the vicinity of Michigamme Mountain, T 44 N, R 31 W, where the Negaunee formation is exposed, a magnetic line extends north through the Sholdice and Doan explorations, where the Negaunee is again exposed, and thence north, northwest, west, and southwest around the great oval anticline into section 27, T 46 N, R 33 W, where it still coincides with the position of the iron formation. A short distance beyond the latter locality the line is broken but it reappears after an interval of about two miles and passes through the Red Rock and Hemlock mines at Amasa and beyond connecting with the iron formation which has been mapped as Vulcan or Upper Huronian.

The U. S. Geological Survey in 1911[1] accepts the conclusion that the magnetic line, exposures, explorations, and drift boulders prove the practical continuity of the Negaunee formation from Michigamme Mountain for a distance of 25 miles around the great anticline to a point about a mile south of section 27, T 46 N, R 33 W, but from a point about two miles further on, through the Red Rock mine and southward, the iron formation is correlated with the Vulcan or Upper Huronian despite the facts (1) of similar position with reference to the underlying Hemlock volcanics, (2) that the strike of the magnetic line north of the Red Rock mine indicates a continuity of the "Vulcan" iron formation there with the Negaunee a little farther north, (3) and that there is no evidence whatever beyond some differ-

*See Smyth's discussion in Mono. 36, U. S. G. S., pp. 452-5

[1]Mono. 52.

ence in degree of metamorphism to show that the iron formations in section 27, T 46 N, R 33 W, and at the Red Rock mine are not one and the same.

The reason why the iron bearing series (Vulcan) of the Crystal Falls-Iron River-Florence district was not correlated with the Negaunee by the U. S. Geological Survey is a simple one. In the Menominee range Van Hise and Bayley found that the iron bearing series is unconformably above a quartzite-dolomite succession similar to the Lower Huronian of the Marquette range and, under the dual classification, therefore Upper Huronian. Since the Negaunee formation had been correlated prior to 1904 with the *Lower* Huronian the question arose as to the position of the iron bearing series in the intervening districts. It was reasoned that (1) because the iron bearing series of the Crystal Falls district was at that time inseparable from the great Upper Huronian slate area opening out south and west from the Marquette district, and (2) because the Hanbury slate of the iron bearing series of the Menominee range seemed to have areal connections with the slates of the Florence-Crystal Falls district, therefore the iron bearing series in the latter district must be considered Upper Huronian. This conclusion was preferred notwithstanding the evidence of continuity of the Vulcan and Negaunee formations in the northern part of the Crystal Falls district and as we shall see became a source of considerable difficulty in applying the dual classification to the facts of succession in the Felch Mountain and Florence districts.

Recent developments in the Hemlock and Michigan mines at Amasa fortunately determines conclusively that the Vulcan iron formation there which has been correlated as Upper Huronian is in reality Negaunee or Middle Huronian. On the thirteenth level of the Hemlock and Michigan mines the folds in the iron formation are truncated by a heavy conglomerate and quartzite carrying fragments of the Negaunee formation of all sizes up to several feet in diameter, including small angular hard jasper fragments, rounded pebbles of chert and ore and great boulders of the iron formation. It is reported that this same conglomerate was found by drilling in similar relations to the iron formation about three miles south of Amasa and in section 36, T 44 N, R 33 W, about four miles further southward. There can be no reasonable doubt that this conglomerate-quartzite is the Goodrich formation of the Marquette range where exactly similar relations are observed.

The productive iron formation at the Hemlock mine extends with only a few unexplored breaks in drift covered country southeastward around the great anticline of Hemlock volcanics and other rocks and is believed to be almost if not quite continuous with the iron formation passing through the Hollister, Armenia, and other mines in the vicinity of Crystal Falls. Such continuity is indicated, so far as definite information is available, by drilling, underground openings and magnetic surveys. Furthermore, the iron formation on the west and southwest sides of the great Crystal Falls oval anticline maintains the same position with reference to the underlying Hemlock volcanics that it does on the north and east sides. Therefore if the iron formation at the Red Rock and Hemlock mines is Negaunee the burden of proof rests on those who would assert in the absence of any supporting facts that the Upper-Middle Huronian unconformity cuts out the Negaunee iron formation and occupies an inferior position with reference to the Vulcan iron formation at any or all points southward. As a matter of fact this practical continuity was accepted by Clements in 1899 and by Leith and Van Hise in 1911 as shown on the maps issued in Monographs 36 and 52 of the United States Geological Survey. In fact Leith and Van Hise argue in this work that the iron formation at the Hemlock mine is *not* Negaunee *on the assumption of practical continuity with the Vulcan formation of the Crystal Falls district to the south and lack of continuity with the Negaunee formation a few miles northward.*

CORRELATION OF THE NEGAUNEE (IRON BEARING) SERIES WITH THE VULCAN (IRON BEARING) SERIES OF THE STURGEON TROUGH, FELCH MOUNTAIN DISTRICT, CALUMET TROUGH, AND MENOMINEE RANGE.

These ranges lie south of the Marquette district and east of the Iron River-Crystal Falls-Florence district and form eastward projecting tongues of the Huronian series of this great area. (See fig. 1.)

1. *Sturgeon River Syncline.* The Negaunee formation has been traced by outcrops, exploration and magnetic surveys from the Marquette Range into the north limb of the Sturgeon River syncline. From near Witch Lake, about eight miles south of Republic, the Negaunee formation is shown by the mapping of the U. S. Geological Survey to rest directly on the Archean. In the Sturgeon syncline, however, the Archean is overlain by the Randville dolomite and Sturgeon quartzite equivalent to the Kona and Mesnard of the Lower Huronian in the Marquette range. On the south limb of this syncline the iron formation reappears above the Randville dolomite and has naturally been correlated with the Negaunee of the north limb.

2. *Felch Mountain District.* The Felch Mountain district is a narrow syncline of Huronian rocks downfolded in the Archean, from one to two miles wide, trending east-west and, like the Sturgeon trough, opening out westward into the great slate area of the Crystal Falls district wherein the structure is obscured. It is separated from the

Sturgeon trough north of it by an anticline on which the Archean appears as a belt of granite about $2\frac{1}{2}$ to 3 miles wide. In the Felch syncline there is an iron formation (Groveland) similar to that in the Sturgeon trough, separated from the quartzite-dolomite below by conformably underlying sedimentary schist (Felch schist) which has not been observed in the Sturgeon trough although it may be present there also. Bayley makes no mention of the Negaunee formation of the Sturgeon trough in 1899* although it was subsequently discovered through exploration and is shown on the maps of the U. S. Geological Survey published in 1911**. On these maps the iron formation in the Sturgeon trough is called Negaunee (Middle Huronian) and, in the Felch syncline, Vulcan (Upper Huronian). This seems to be a purely arbitrary classification but it fulfils the necessity under the old correlation of making the jump *somewhere* from the Negaunee of the Sturgeon trough to the Vulcan of the Menominee range. The Felch schists were regarded by the U. S. Geological Survey as Upper Huronian because they open out and seem to connect with sediments to the west which had been correlated as Upper Huronian although the area in which the connection is indicated is deeply drift covered and wholly devoid of rock exposures. But even if this connection were a fact, as it may well be, it appears *now* that it constitutes merely an added reason why the Groveland iron formation should be correlated with the Negaunee since the Crystal Falls slate-iron formation series has been shown to be more probably *Middle* rather than Upper Huronian.

As a matter of fact Smyth *did* correlate the Groveland with the Negaunee formation in 1899 but after Seaman's discovery of the unconformity at the base of the Ajibik quartzite necessitated the correlation of the Negaunee series with the *Middle* Huronian (1904) Van Hise and Leith in 1911 took the Groveland out of the *Lower* Huronian and placed it in the *Upper* Huronian. In order to make this change it was necessary to assign a highly metamorphic quartzite-mica schist series which is unconformably *above* the Groveland to the Keweenawan or Paleozoic for the reason that no place was then left for it in the Huronian group. Smyth was obviously right in correlating the Groveland with the Negaunee formation. The quartzite-mica schist series above the Groveland bears no resemblance to the Keweenawan or Paleozoic. It is Huronian and we believe, should be correlated with the Copps, part of the Michigamme and the Princeton series. The quartzite which is unconformably above the slate-iron formation series (Animikie) of the Florence district is similarly correlated.

3. *Calumet Trough.* In the Calumet trough, about four miles south

*Monograph 36, U. S. Geological Survey.
**Monograph 52.

of the Felch syncline, the situation is practically identical with that in the Felch Mountain district, and the same arguments for revision of the correlation apply here as in the Felch district. In other words, the iron formation now assigned to the Upper Huronian is believed to be really an equivalent to the Negaunee of the Middle Huronian. Rocks similar to the quartzite-mica schist series of the Felch syncline are exposed at the old Hancock exploration in T 41 N, R 27 W, and in at least one or two places near the southern edge of the Calumet trough. Each of the three Huronian series seems to be represented here exactly as in the Felch syncline a few miles north.

4. *Menominee Range.* The general similarity of the iron bearing series of the Menominee district with that in the Sturgeon, Felch, and Calumet troughs and in turn with certain phases of the Negaunee formation of the Marquette district, its similarity in relation to the underlying Lower Huronian and its areal connections with the great slate-iron formation series of the Florence-Crystal Falls district determine that the Vulcan of the Menominee range is probably of Negaunee age, that if the iron formation in the districts intermediate between the Menominee and the Marquette ranges is Negaunee, there is no basis on lithological, structural, or other grounds for assigning the iron formation of the Menominee range to any horizon other than Negaunee, i. e., Middle Huronian.

Leith has described a remnant of cherty quartzite, of a maximum thickness of 70 feet, lying apparently unconformably between the Randville dolomite below and the Traders member of the Upper Menominee series above in the vicinity of Norway* but he places no emphasis on it so far as concerns its significance in the correlations. This formation according to the more recent opinion of Dr. Leith** is a remnant of regolith unremoved by erosion in Lower-Middle Huronian time.

CORRELATION OF THE IRONWOOD SERIES (ANIMIKIE) OF THE GOGEBIC RANGE WITH THE VULCAN (MIDDLE HURONIAN) SERIES OF THE CRYSTAL FALLS-IRON RIVER-FLORENCE-MENOMINEE DISTRICT ON THE BASIS OF SIMILAR RELATIONS TO INTRUSIVE GRANITE.

Area southeast of the Gogebic range including Marenisco, Turtle, Manitowish, Vieux Desert, Conover, Iron River, Crystal Falls, and Menominee Districts. Probably the most striking feature of the Middle Huronian (Animikie) of these districts is the general prevalence of intrusive granite. Heretofore these granites have been variously correlated, from

*Monograph 52, U. S. Geological Survey, pp. 234-5
**As expressed in conversation with the writer.

Laurentian in the Gogebic, northern Wisconsin, and Menominee districts, through the Upper Huronian in the Crystal Falls district to Keweenawan in the Florence-Menominee and northeastern Wisconsin areas.

In the Menominee district Bayley found that the granite south of the Menominee River intrudes a series of basic volcanics called the Quinnesec schist which he correlated erroneously with the Keewatin. Although it was realized that the correlation of the Quinnesec schist as Keewatin introduced a conception of structure quite out of accord with natural inferences on the basis of the facts, it remained for Corey and Bowen, working under the direction of Van Hise and Leith, in 1905* and Hotchkiss in 1910** to show conclusively that the Quinnesec schist is partly intrusive into but in greater part interbedded with the upper part of the Upper Huronian†, i.e. Animikie†.

Inasmuch as the granite was thus proven to be the youngest rock in these districts, and the youngest pre-Cambrian sediments had been correlated with the *Upper* Huronian, Leith and Van Hise in 1911†† correlated the granite with the Keweenawan and extended the boundaries south and east to include several thousand square miles of acid intrusives in north central Wisconsin which had been mapped and described by Weidman in 1905†††.

It is interesting to note here that Brooks and Wright had correctly interpreted these relations as early as 1876, although they did not, at that time at least, comprehend the great mass of the intrusive granite. To quote from Brooks:"In the summer of 1874 Chas. E. Wright and myself exploring the country west and south of the Menominee River about 90 miles from its mouth, under the auspices of the Wisconsin Geological Survey, observed a large granite area, the north edge of which was bounded by dark colored hornblendic and micaceous schists of Huronian age, which I have since concluded are equivalents of the youngest member of that series yet observed in the Marquette iron region . . . . . The lithologic character of this wide granite belt bore so much resemblance to the Laurentian rocks, which are extensively developed on the waters of the Sturgeon River in Michigan, 10 to 20 miles to the northeast, that we were disposed at the time to believe that some phenomena of folding or faulting had brought rocks belonging to that system to the surface in an unexpected quarter. Professor Pumpelly and myself, several years previously had observed, farther to the north and west, similar granite rocks crossing the Michigamme and Paint rivers (branches of the

*Unpublished notes of field work done in 1905 by G. W. Corey and C. F. Bowen.
**Unpublished field notes of W. O. Hotchkiss.
†Middle Huronian of this article.
††Mono. 52, U. S. G. S.
†††The Geology of North Central Wisconsin, by S. Weidman, Bull. Wis. Geol. & Nat. Hist. Survey No. 16, 1907.

CORRELATION TABLE.

Showing changes in Huronian correlation on the basis that the Animikie Series is Middle Huronian.

	Marquette	Gwinn	Sturgeon	Felch Mountain	Calumet	Menominee	Florence	Crystal Falls	Iron River	Vieux Desert Conover	Mantowish	Turtle	Marenisco	Gogebic	Cuyuna	Mesabi	Vermilion	Gunflint Lake	[illegible]
Upper Huronian	Greenstone intrusives and extrusives Michigamme slate (partly replaced by Clarksburg volcanics) Bijiki schist (iron-bearing) Goodrich quartzite	Michigamme slate Goodrich graywacke and conglomerate	Micaceous quartzite and slate	Mica schist Ferruginous and micaceous quartzite			Quartzite and conglomerate	Michigamme slate	Michigamme slate					Copps formation (Conglomerate, graywacke and slate.)					
Middle Huronian	Negaunee iron formation Siamo slate Ajibik quartzite	Slate Negaunee iron formation Slate Arkose conglomerate	Iron formation (Negaunee	Vulcan iron formation Felch schist	[illegible] slate [illegible] iron [illegible]ation [illegible] schist	Granite Quinnesec schist Hanbury slate Vulcan iron formation	Granite Quinnesec schist Hanbury slate Vulcan iron formation	Paint slate? Greenstone intrusives and extrusives Hanbury slate Vulcan-Negaunee iron formation Ajibik quartzite Mansfield slate Hemlock volcanics	Paint slate? Greenstone intrusives and extrusives Hanbury slate Vulcan iron formation Slate	Granite Slate and schist	Granite Kyanitic biotitic garnetiferous and graphitic schists Iron formation (Amphibole-magnetite rocks.)	Granite Greenstone intrusives and extrusives Slate Iron formation Slate Quartzite	Presque Isle granite Greenstone extrusives and intrusives Slate Iron formation Graywacke and quartzite	Presque Isle granite Tyler slate Greenstone extrusives Ironwood iron formation Palms formation (quartzite and quartz slate	Base[illegible] intr[illegible] extr[illegible] Virg[illegible] Lou[illegible] Deer[illegible] for[illegible] Slat[illegible] Quar[illegible]	Embarrass granite? Acidic and basic intrusives Virginia slate Biwabik iron formation Pokegama quartzite	Rove slate Gunflint iron formation	Rove slate Gunflint iron formation	Black slate Iron formation
Lower Huronian	Wewe slate Kona dolomite Mesnard quartzite		Randville dolomite Sturgeon quartzite	Randville dolomite Sturgeon quartzite	[illegible] dolomite [illegible]ite	Quartzite Randville dolomite Sturgeon quartzite			Dolomite and quartzite (Saunders formation.)			Dolomite Dolomitic quartzite		Bad River Limestone Sunday quartzite		Giants Range granite Graywacke conglomerate	Granite, dolomites, lamprophyres, other intrusive rocks below Knife Lake slate Agawa formation Ogishke conglomerate.	Greenstone and granite intrusives Graywacke	Granite and greenstone intrusives [illegible] conglomerate
Archean — Laurentian	Granite, granite porphyry, Palmer gneiss	Granite	Granite and gneiss	Granite and gneiss	[illegible]te and [illegible]s	Granite and gneiss							Amphibolite Granite and gneiss	Granite and gneiss		Granite and porphyries	Granite and other intrusives Soudan iron formation	Granite and gneiss	Granite and gneiss
Keewatin	Kitchi and Mona schist					Green schist			Greenstone greenschists and tuffs					Greenstone, greenschist and slate		Greenstone, hornblende schists and porphyries	Ely greenstone	Greenstone, greenschist Mashed porphyries	Greenstone, greenschist Mashed porphyries

Menominee) presenting similar puzzling relations with beds known to be Huronian, and younger as well as lithologically different from any rock then known to be of that period.

"A careful consideration of all of the facts to be observed in the Menominee region confirms me in this hypothesis, ..."*. The conclusion of Brooks is confirmed by the work of Hotchkiss in the Florence district of Wisconsin in 1910†.

In 1911-14 the writer and assistants, through field mapping and diamond drilling, traced what appears to be this same granite from the Iron River district westward through the Animikie series of the Vieux Desert-Conover district and Manitowish, Turtle, and Marenisco ranges, in all of which it is in intrusive relation with the sediments, and connected it with the "eastern Laurentian area" of Van Hise and Irving on the eastern Gogebic range which was considered by these geologists to form a part of the Archean basement complex whereas it actually intrudes the Lower and Middle Huronian (Animikie) series and is unconformably overlain only by the Upper Huronian (Copps) series. *Thus the great granite batholith of Northern Wisconsin has been fairly demonstrated to be not only in intrusive relations with the Animikie sediments over several thousands of square miles but also to be overlain unconformably by a pre-Cambrian series which is unconformably below the Keweenawan.*

Inasmuch as the Vulcan (Animikie) series of the Crystal Falls, Iron River, Menominee, Florence and other Michigan districts has been shown to be very probably equivalent to the Negaunee series of the Marquette range and the Ironwood series of the Gogebic range, the age of this great granite batholith and its outliers may be considered as late Middle Huronian.

GENERAL REMARKS ON THE CORRELATION OF THE ANIMIKIE SERIES WITH THE MIDDLE HURONIAN.

The correlation of the Animikie series with the Middle Huronian eliminates what would otherwise be the necessity of assuming a *fourth* Huronian series of which the Copps formation of the Gogebic range would be the sole representative. The practical identity of the Huronian succession of the Gogebic and Marquette ranges together with the marked similarity of the Copps formation and the Upper Huronian of the Marquette and Gwinn districts is an adequate basis for moving the Animikie of the Michigan and other Huronian districts downward into the Middle Huronian, particularly as this correlation, as we have seen, eliminates what would otherwise be a further necessity of including the uppermost series of metamorphic sediments in the Felch, Cal-

*On the youngest Huronian rocks south of Lake Superior and the age of the copper bearing series, by T. B. Brooks. Am. Jour. Sci. Vol. 11, 1876, pp. 206-7.

†Unpublished manuscript.

umet, and Florence districts in the Keweenawan or the Paleozoic where they obviously do not belong.

The anomalous position in the correlations of the great Negaunee iron bearing series has been unsatisfactory to a great many students of the pre-Cambrian for many years.[1] We now have a firm basis for the correlation of the Negaunee series with the great productive iron bearing series of the Animikie of all of the other districts of the Lake Superior region and are able to recognize the consideration that the unique conditions which resulted in the deposition of the great Huronian iron formations were regional rather than local and should be correlated in time. While it is true that the names now used have come to have well understood significance because of long usage, it can not be held that this is a valid argument for the retention of a classification which no longer correctly interprets the facts of present knowledge.

[1]See Geological section of Michigan, A. C. Lane and A. E. Seaman, Mich. Geol. Survey, Annual Report, 1908, pp. 23-30. Lane and Seaman correlate the Animikie iron-bearing series of Michigan throughout with the Negaunee iron-bearing series (Middle Huronian) of the Marquette range.

CHAPTER III.

A REVISION OF THE SEQUENCE AND STRUCTURE OF THE PRE-KEWEENAWAN FORMATIONS OF THE EASTERN GOGEBIC IRON RANGE.

R. C. ALLEN AND L. P. BARRETT.

INTRODUCTORY STATEMENT.

In this chapter there is presented the results of recent studies of the geology of the Gogebic iron range from T 47 N, R 45 W, east to Gogebic lake, a distance of 15 miles.

Former interpretations of the geology of the Gogebic iron range are based almost entirely on early investigations of the United States Geological Survey*. Prior to 1914 four years of study of the pre-Cambrian of the region south and east of Gogebic Lake to the Iron River district, including 38 townships adjacent in northern Wisconsin, by the senior writer and his assistants had failed to establish a satisfactory basis of correlation with the rocks of the Gogebic range. (Fig. 1.) Inasmuch as recent drilling for iron ore has supplied important information, unavailable to earlier workers in this field, it was thought that a field study of the eastern Gogebic iron range would probably alter former interpretations of the geology and furnish a better basis of correlation with the pre-Cambrian terranes of adjacent territory and the Lake Superior region. The results of our studies are more satisfactory than we had anticipated and we believe are of considerable importance to the progress of pre-Cambrian geology.

We acknowledge our indebtedness to Dr. C. R. Van Hise for placing in our hands his early field notes and plats, to Dr. C. K. Leith for helpful suggestions in field conference, to Mr. Robert Selden Rose of Marquette, Messrs. Luther Brewer and George Rupp of Ironwood, and the Presque Isle Mining Company for records of drilling and underground exploration.

SUMMARY OF THE GEOLOGY BASED ON EARLIER WORK.

Van Hise and Leith have recently presented the views of the United States Geological Survey† which may be briefly summarized.

*Monograph 19, United States Geological Survey, C. R. Van Hise and R. D. Irving.
†Monograph 52, United States Geological Survey.

The Huronian rests on the Archean with profound unconformity and is represented by two unconformable sedimentary series, the Upper and the Lower Huronian, which are in approximate structural parallelism and dip steeply northward beneath the Keweenawan.

The Archean comprises a green schist series (Keewatin) intruded by granite (Laurentian).

The Lower Huronian has two members, a basal quartzite (Sunday) and an upper cherty dolomite (Bad River).

The geology of the "Upper Huronian (Animikie) Group of the Eastern Area" is summarized in the following words:

"In the eastern part of the district—that is, from about 6 miles east of Sunday Lake to Lake Gogebic, the Upper Huronian rocks have an exceptional character. In the larger part of the district the conditions were those of quiet sedimentation but in the eastern area throughout the greater part of the Upper Huronian there was continuous volcanic action. In consequence the rocks are lava flows, volcanic tuffs, conglomerates, agglomerates, and slates, with all sorts of gradations, just such as one would expect if a volcano rose in a sea and volcanic action continued for a great period. Naturally in this area it is not possible to map any continuous sedimentary belts. The dominant rocks are greenstone conglomerates and lavas and massive eruptives. The uppermost formation for the extreme eastern part of the area is ferruginous slate. This ferruginous slate, though dominantly clastic, contains narrow bands of non-clastic sediments such as chert, cherty ferro-dolomite, ferro-dolomitic chert. *It is believed that the ferruginous slate is probably at the same horizon as the Ironwood formation to the west and that its dominant fragmental character is due to the presence in this area of one or more volcanic mountains which arose above the water and upon which the waves were at work after the close of the period of active volcanic outbreaks.*"†

SUMMARY OF THE WRITERS' CONCLUSIONS.

The writers' most important conclusions, insofar as they differ from those of the earlier writers as summarized above, may be stated briefly as follows:

1. Huronian. *There are three unconformable sedimentary groups in the Huronian series.* The formations heretofore included in the Upper Huronian group are divisible into two groups separated by an unconformity of the first magnitude. For the superior group we propose the name Copps in recognition of the important exposures of its basal horizons near the old Copps mine.

2. Archean. *The granite heretofore described as Laurentian not only*

†Writers' italics.

intrudes the Keewatin but also cuts across two great unconformities into the Animikie group (Middle Huronian).

3. *The unconformity between the Copps formation and the Middle Huronian (Animikie) group is one of great angular and erosional magnitude* and is of greater importance to this district, measured by the usual criteria for evaluation of breaks in pre-Cambrian sedimentary successions, than either the unconformity separating the Keweenawan and Huronian or the one separating the Animikie and Lower Huronian.

For convenience of reference and greater clearness in the discussions which follow we introduce the successions of the United States Geological Survey and the writers' in parallel columns.

CORRELATION TABLES. GOGEBIC IRON RANGE.

	By U. S. Geological Survey, 1911.		By Michigan Geological Survey, 1914	
	West of center of T 47 N, R 44 W.	East of T 47 N, R 45 W		East of T 47 N, R 45 W.
Quaternary System Pleistocene series	Glacial deposits	Glacial deposits		Glacial deposits
Cambrian System		Unconformity Lake Superior sandstones		Unconformity Lake Superior sandstone (doubtful)
Algonkian System Keweenawan series	Unconformity Gabbro, diabase, basic lavas, conglomerate, etc.	Unconformity Gabbro, diabase, basic lavas, and interbedded sandstone and conglomerate		Unconformity Gabbro, diabase, basic lavas, interbedded sandstone and conglomerate, and basal conglomerate.
Huronian Series Upper Huronian (Animikie)	Unconformity Greenstone intrusives and extrusives. Tyler slate Ironwood formation (iron bearing) Palms formation	Unconformity Extrusive and intrusive greenstone. Palms and Ironwood formations represented by ferruginous slate, graywacke and quartzite	Upper Huronian	Unconformity Copps formation. Ferruginous slate, graywacke, chert, and basal conglomerate.
			Middle Huronian (Animikie)	Unconformity Granite Extrusive and intrusive greenstones Ironwood formation (iron bearing) Palms formation
Middle Huronian				
Lower Huronian	Unconformity Bad River limestone Sunday quartzite	Unconformity Bad River limestone Sunday quartzite		Unconformity Bad River limestone Sunday quartzite
Archean System Laurentian series	Unconformity Granite & granitoid gneiss	Unconformity Granite and granitoid gneiss		Unconformity
Keewatin series	Greenstone and greenschist	Greenstone and greenschist		Greenschist

ARCHEAN SYSTEM.

The rocks of Archean age include only the fine grained chlorite schists in the west half of T 47 N, R 44 W, which are unconformably beneath the Sunday quartzite of the Lower Huronian. In the reports of the U. S. Geological Survey* the hornblende-mica schists and gneisses lying south of the Huronian sediments in T 47 N, R 43 W, (Fig. 2) are included in the Keewatin and the extensive area of acid intrusives, to which the name Presque Isle granite is here given, is placed in the Laurentian. It will be shown later that the Presque Isle granite intrudes the Middle Huronian (Animikie) and that the schists in T 47 N, R 43 W, heretofore correlated with the Keewatin, are metamorphic phases of the Palms formation. The Presque Isle granite may include Laurentian rocks but it seems clear that the greater part of it is of late Animikie age. Farther west, however, the base of the Huronian series rests unconformably upon Laurentian granite.

ALGONKIAN SYSTEM.

HURONIAN GROUP.

Lower Huronian Series.

The Lower Huronian comprises two formations, viz, the Sunday quartzite and the Bad River limestone, exposures of which are confined to a prominent hill in the south half of sections 17 and 18, T 47 N, R 44 W. The persistence of the Lower Huronian east of section 17 is problematical (See map, Fig. 2 A and Fig. 2 B).

SUNDAY QUARTZITE.

Lithology. The Sunday quartzite is made up of a basal conglomerate from a few inches to ten feet thick overlain by about 150 feet of quartzite. The conglomerate contains pebbles of vein quartz, greenstone, and granite, fragments of red feldspar, and occasional pebbles of gray cherty siliceous material. The vein quartz pebbles are the most abundant. The matrix of the conglomerate is composed mainly of particles of chlorite, feldspar and quartz.

The Sunday quartzite is a rather coarse grained aggregate of rounded grains of quartz and feldspar, the latter very subordinate in quantity. Near the base it has a greenish tinge on fresh fracture but grades rapidly up into a grayish white or slightly pinkish rock. The formation dips north at angles of 30° to 40°.

Relations to Adjacent Rocks. The Sunday Quartzite is separated

*Monographs Nos. 19 and 52.

from the underlying Keewatin greenschists by a great unconformity. The actual contact between the two formations (see Fig. 2) is exposed for a distance of 50 paces at the base of the prominent bluff near the north line of the SW¼ of SE¼ of section 18. The green schist at this locality has a nearly N-S strike and a vertical dip. It is abruptly overlain by the southeasterly striking and northerly dipping quartzite. It is apparent from these relations that the greenstone had been folded, metamorphosed, uplifted, eroded and base leveled prior to the deposition of the Lower Huronian.

The Sunday quartzite grades upward into the Bad River limestone.

BAD RIVER LIMESTONE.

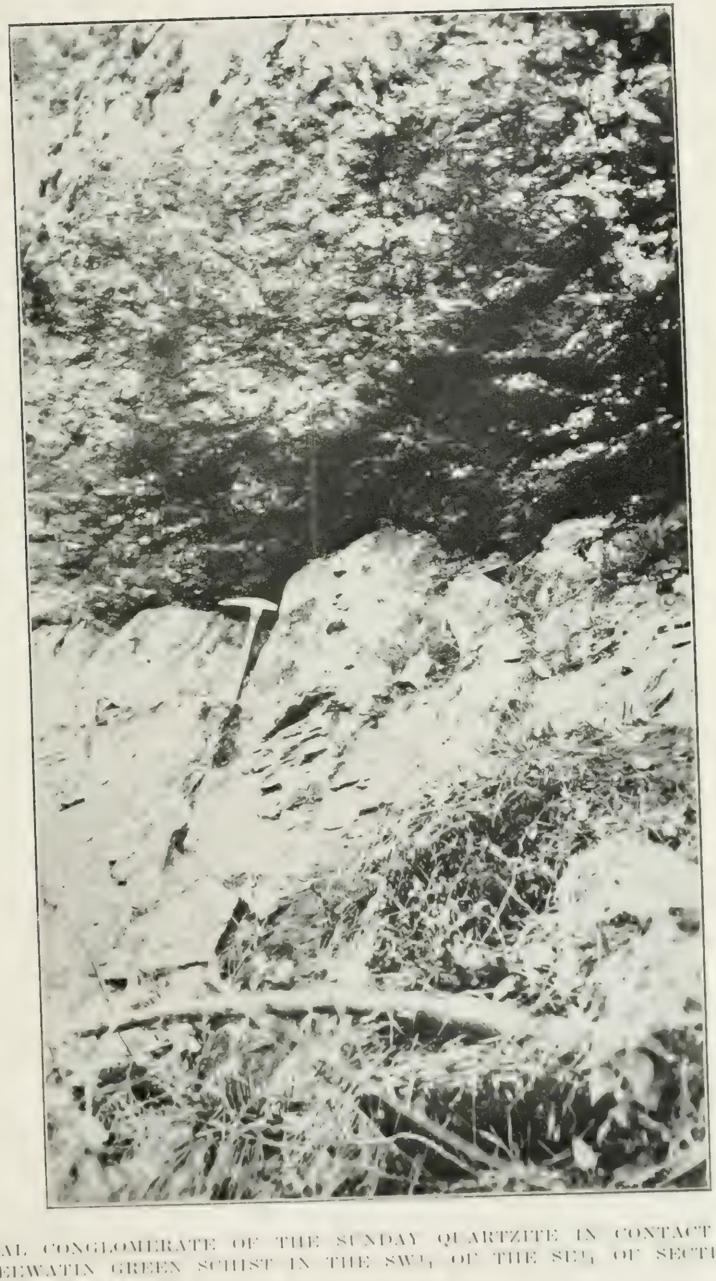
Lithology. This formation is described by Van Hise and Leith as follows:** "The formation is called a limestone because that is the predominant rock. The limestone is heavily magnesian and in places approaches a dolomite. It commonly bears silicates of which tremolite is the most abundant, but chlorite and sericite are not uncommon. The rock is very siliceous. The coarsest varieties are quartz but chert is more common. In many places the silica is closely intermingled with the dolomite. In other places it occurs in bands varying from a fraction of an inch to much greater width, and in one place a band of siliceous material 45 or 50 feet wide was observed. Thus the chert and limestone are intermingled and interstratified. The cherty limestone is a water deposited sediment. Whether the original carbonate was of chemical or organic origin we have no definite evidence, but there is no more reason to suppose that life was not concerned in the deposition of this cherty limestone than of those of later age.

"The Bad River limestone has been much metamorphosed since its deposition. During its metamorphism the silica recrystalized. It was concentrated into bands. It was arranged into veinlike forms. During these changes a part of the silica may have been introduced from extraneous sources or at least from parts of the formation now removed by erosion. The abundant tremolite is evidence that the metamorphism took place under deep seated conditions when the silica united with the calcium and magnesium to form silicates, the carbon dioxide being released at the same time. This is an anamorphic change that took place with a decrease of volume."

Middle Huronian (Animikie).

Introductory statement. The Upper Huronian is represented on the east end of the range by the Palms quartzite and the Ironwood iron

**Monograph 52, U. S. Geological Survey.



BASAL CONGLOMERATE OF THE SUNDAY QUARTZITE IN CONTACT WITH KEEWATIN GREEN SCHIST IN THE SW¼ OF THE SE¼ OF SECTION 18, T. 47 N., R. 44 W.

bearing formations, volcanic agglomerates, breccias and flows and intrusive granite (Presque Isle) and greenstone.

The Palms formation is composed mainly of quartzite, quartz slate and graywacke; the Ironwood formation is mainly non-clastic and is composed of ferruginous chert, cherty iron carbonate, iron ore and locally amphibole-magnetite rocks. Slate becomes increasingly important in the Ironwood formation east of Sunday Lake.

Throughout the central part of the Gogebic range the Middle Huronian includes a third formation, the Tyler slate, a pelite or mud formation of immense thickness. It is cut out east of Sunday Lake by erosion and the great Wakefield thrust fault and apparently does not appear on the east end of the range.

In the maps accompanying the reports of the U. S. Geological Survey the Palms and Ironwood formations are carried as cartographic units eastward to section 22, T 47 N, R 44 W, where, with the exception of isolated patches of iron formation which are correlated with the Ironwood, a new unit representing ferruginous slates is introduced to carry their combined stratigraphic horizons to the east extremity of the range. As a result of the field work of the Michigan Geological Survey the Palms and Ironwood formations have been traced in typical development as far east as section 23, T 47 N, R 43 W, where they disappear, *not through lithologic gradation* into ferruginous slate but by *abrupt truncation by a superior unconformable series.* The major portion of the ferruginous slate belt of the U. S. Geological Survey is unconformably above the Palms and Ironwood formations of the Animikie group and has been separated in mapping and named Copps formation in recognition of the important exposures in the vicinity of the old Copps mine. The essential changes in mapping and interpretation may be seen by a comparison of the map accompanying this report with those found in the reports of the U. S. Geological Survey*.

Relations to adjacent formations. The Lower Huronian is overlain unconformably by the Palms formation of the Middle Huronian. The evidence of this relationship does not refer to any one locality but is based largely on general field relations, and particularly upon a lack of continuity of the Lower Huronian formations which is believed to be due to erosion preceding the deposition of the Upper Huronian. Van Hise and Leith** summarize the evidence as follows: "The fact that where the belt of conglomerate at the base of the Palms lies above the Bad River limestone it bears much detritus from that limestone shows that the limestone after deposition became indurated and was eroded before Palms time. In general, the strikes and dips of the two

*Monographs 19 and 52.

**Monograph 52, U. S. G. S., page 230.

formations are approximately parallel, as are those of correlated formations in the Menominee district, but it is plain that the erosion was sufficient to remove the major portion of the Bad River limestone and also any later formations that may have been deposited in the Lower Huronian. The lack of marked discordance in the bedding of the Bad River limestone and the Palms formation is no evidence that the time gap between the two was not long enough to have produced a pronounced discordance elsewhere, for the Penokee district at this time may have been distant from areas of important folding and thrusting which elsewhere may have occurred."

PALMS FORMATION.

Distribution and exposures. The Palms formation is exposed in a few outcrops and many test pits south of the iron formation in sections 17, 18 and 21, T 47 N, R 44 W. East of section 21 for a distance of about three and one-half miles there are no exposures. Near the center of section 30, T 47 N, R 43 W, and thence northeast to the NE$\frac{1}{4}$ of NW$\frac{1}{4}$ of section 23, exposures in outcrops and test pits are fairly plentiful. The outcrops and test pits along the N-S quarter-line through the south half of section 21 and the north half of section 28 afford an excellent cross section for study, especially of the progressive metamorphism of this formation toward the contact with the Presque Isle granite. Near the center of the NE $\frac{1}{4}$ of section 21 the upper quartzite horizon is exposed in outcrops and test pits adjacent to the iron formation. Recent drilling in sections 21 and 22 has served to define more accurately the position of the Palms formation and in addition has furnished data without which it would be impossible to obtain a clear idea of its structure in that vicinity.

Lithology. Throughout the Gogebic range the Palms formation maintains a characteristic succession of members.

The base is nearly everywhere marked by a thin conglomerate one to three feet thick. Where the formation is in contact with the Archean the pebbles are granite, gneiss, and greenschist, but where the underlying formation is the Bad River limestone the conglomerate also include fragments of chert and limestone. In a few localities the conglomerate contains scattered jasper fragments.

The central part of the formation is a graywacke quartz slate member from 350 to 500 feet thick. This member comprises many facies, including fine grained slate, novaculite, graywacke, and quartz slate. In the upper horizons thin layers of quartzite become increasingly important and mark the change in conditions of sedimentation leading to the deposition of the upper quartzite member.

The upper part of the Palms formation is a massive, light colored vitreous quartzite from 50 to 150 feet thick, of very uniform texture and composition. Near the contact with the overlying iron formation the quartzite is stained brownish red with hematite.

From the west line of T 47 N, R 44 W, east to section 22 the Palms formation maintains its general character and merits no special description. The test pits and outcrops indicate graywacke and quartz slate overlain by quartzite. Its thickness in this locality is probably in the neighborhood of 500 to 600 feet.

Metamorphic Phases of the Palms Formation. In T 47 N, R 43 W, the Palms formation possesses an exceptional character and merits detailed treatment. The upper quartzite is persistent and easily recognized but the base of the formation grades irregularly into micaceous and hornblendic schists toward the contact with the Presque Isle granite.

In the south half of section 21 and the north half of section 28 the upper quartzite member is exposed in numerous outcrops, especially near the center of section 21 immediately south of pits in iron formation. The upper horizon is massive, grayish white to pink and even grained but near the contact with the Ironwood formation it is dark red. Beneath the massive upper horizon thin beds of slate become increasingly important. About 250 paces south of the center of section 21 there are abundant exposures consisting of alternate layers of quartzite and slate averaging from one to four inches thick. The rock is highly contorted, the axial planes of the minor folds dipping southward. The slate bands exhibit well developed schistosity also dipping south. The formation as a whole appears to be inclined steeply northward. The quartzite bands are microscopically very similar to those from the upper member although there is a slight increase in the content of feldspathic material. Quartz in stringers and veins is a conspicuous feature of the rock in these exposures.

Southward for a distance of about 500 paces outcrops are lacking, but the rocks are well exposed in exploration pits. The dumps of these pits contain purple and gray slate and graywacke. In some of them thin seams of quartzite are indicated. The coarser layers are composed of grains of quartz, feldspar, and lesser amounts of chert and biotite imbedded in a fine grained matrix of smaller fragments of the same materials and a large amount of sericite and chlorite. The more slaty phases are composed of a felty mass of chlorite, sericite and fine grained limpid material, probably quartz and feldspar. A clastic texture is indicated only by the presence of widely scattered large rounded grains of quartz or feldspar. The accessory minerals are ferrite, epidote, rutile, and rarely magnetite and tourmaline. Quartz is the most abundant mineral but feldspar is common, including orthoclase, plagioclase, and microcline. The clastic biotite is more often visible macroscopically than microscopically. It occurs as flat rounded flakes on the cleavage surfaces of the slate to which it imparts a characteristic shimmer. In general it may be stated that these rocks do not differ in mineral composition or texture from similar exposures of the Palms formation in other parts of the range. Their composition indicates derivation predominantly from acid granite. The fragmental chert is probably derived from the Bad River formation.

Southward from about 250 paces north of the south ¼ post of section 21 the rocks gradually lose their sedimentary textures and become hornblendic and micaceous. This change is accompanied by an increasing abundance of secondary quartz, the occurrence of pegmatite veins and sudden change of strike and dip. Near the Presque Isle granite the rock becomes a hornblende gneiss or mica schist cut by numerous veins of pegmatitic and granitic material. Many of these veins are parallel to the gneissosity while others cut across it indifferently.

Under the microscope the change is first manifest by the appearance of secondary biotite, small scattered needles of hornblende, or both, and by the increase in importance of the epidote and titanium minerals. The finer grained bands are recrystalline but the coarser bands retain in part their sedimentary appearance in the rounded outlines of the larger grains. A short distance farther south the hornblende becomes increasingly more important and is easily visible in hand specimen while the quartz and feldspar interlock in a crystalline aggregate in which all suggestion of sedimentary texture is obliterated. The number of secondary minerals increases and finally includes epidote, leucoxine, ferrite, sericite, chlorite, pyrite, tourmaline, apatite and rutile.

On maps of the U. S. Geological Survey these hornblende and mica schists and gneisses are included in the Keewatin. It has been shown, however, that there are all possible gradations between them and the graywackes and slates readily recognizable as belonging to the Palms. On the N-S quarterline at the locality just described exposures are exceptionally numerous and the gradational change from graywacke to hornblende gneiss is unmistakable. This exceptional metamorphism of the Palms formation is believed to be the result of intrusion by the Presque Isle granite. Further evidence of granitic intrusion will be presented later.

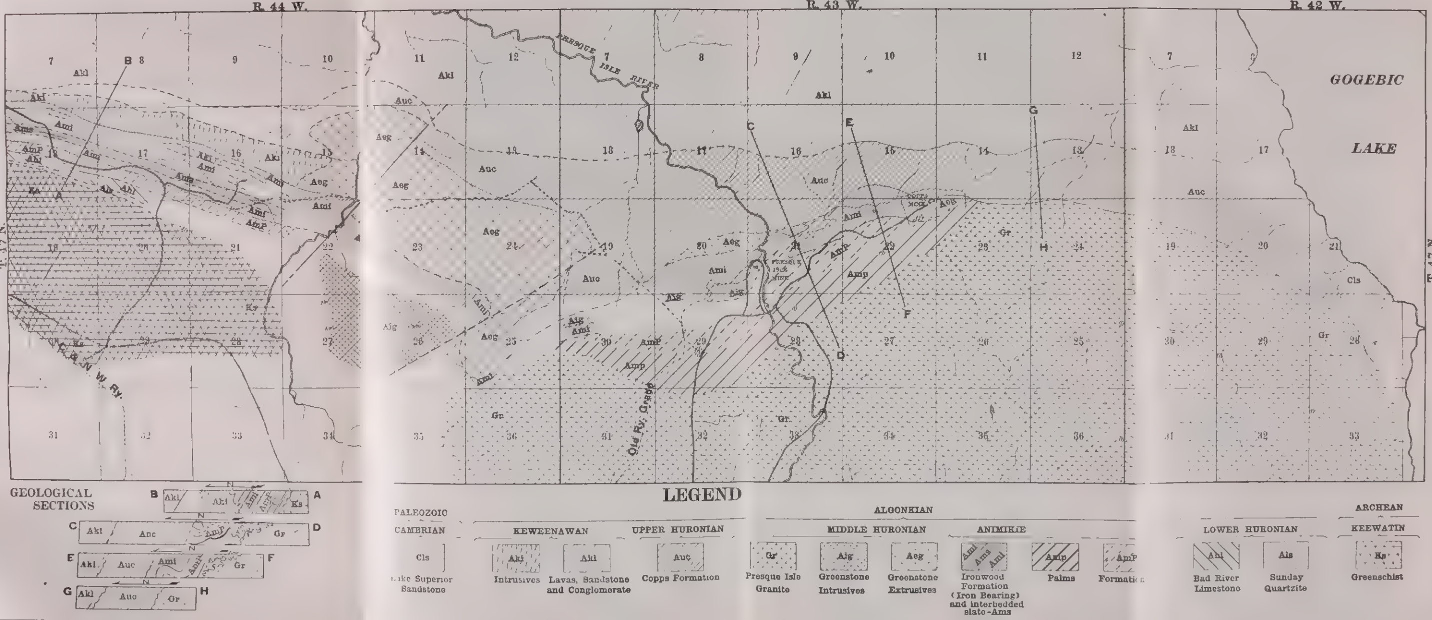
Exposures of the Palms formation occur at a number of other localities in T 47 N, R 43 W, but nowhere else is the section so complete nor can the progressive metamorphism of the Palms formation in approaching the contact with the Presque Isle granite be so well observed. The rocks at these localities are similar to those in the typical section just described.

It is not possible to determine accurately the thickness of the Palms

Fig. 2 A.

GEOLOGICAL MAP OF THE EAST END OF THE GOGEBIC IRON RANGE, MICHIGAN.

BY R. C. ALLEN AND L. P. BARRETT.



formation in T 47 N, R 43 W, on account of intense folding and intrusion. It may be thicker here than elsewhere, but the apparent increase in thickness is probably to be accounted for by repetition of beds by folding.

Relations to adjacent formations. The relations between the Palms formation and the Bad River limestone of the Lower Huronian have already been discussed.

The Presque Isle granite, formerly considered as Laurentian, intrudes the Palms. A discussion of this relationship will be given in connection with a description of the Animikie intrusives.

The Palms formation is conformably overlain by the Ironwood formation. In places the base of the latter is marked by a thin conglomerate which, however, is not believed to mark a break in sedimentation of any great significance. The change from fragmental sedimentation of Palms time to the non-fragmental deposition of Ironwood time was relatively sudden although there appears to be some evidence of the approach of this change in the cherty matrix of portions of the upper horizons of the Palms quartzite.

IRONWOOD FORMATION.

Distribution and exposures. In the latest maps of the U. S. Geological Survey* the Ironwood formation is carried as a continuous formation as far east as the northwest corner of section 22, T 47 N, R 44 W. East of this locality small patches of iron formation are indicated in the NW$\frac{1}{4}$ of section 15, near the W$\frac{1}{4}$ post of section 14, near the W$\frac{1}{4}$ post of section 23, and in the SW$\frac{1}{4}$ of section 25, T 47 N, R 44 W. In T 47 N, R 43 W, iron formation is noted in the east portion of section 30, S half of section 20, NE$\frac{1}{4}$ of section 21, and in the NE$\frac{1}{4}$ of section 22.

The recent work of the Michigan Geological Survey warrants a number of important changes in the mapping of this formation. On the accompanying map (fig. 2) we have shown the areas known to be underlain by iron formation and have indicated probabilities of extension in territory devoid of conclusive evidence.

With regard to the patches of iron formation located on the U. S. Geological Survey maps in sections 14 and 15, T 47 N, R 44 W, it may be stated that the evidence in section 15 consists of a group of pits ledged in black slate. The dumps of these pits contain also a small amount of magnetic slate and ferruginous chert. The exact age of these rocks is problematical but on the basis of their position and lithologic character it is probable that they belong to the Copps (post-Animikie) formation rather than to Ironwood. We were unable to

*Monograph 52, U. S. Geological Survey.

find any field evidence of the existence of iron formation in the east half of section 14, and careful search in the original field books of the U. S. Geological Survey failed to find any evidence of the existence of pits or outcrops of iron formation or associated rocks. It is therefore probable that the patch of iron formation in this section is to be attributed to an error in printing the map.

The Ironwood formation does not appear east of the NE$\frac{1}{4}$ of section 23, T 47 N, R 43 W, where it was truncated by erosion preceding the deposition of the Copps formation.

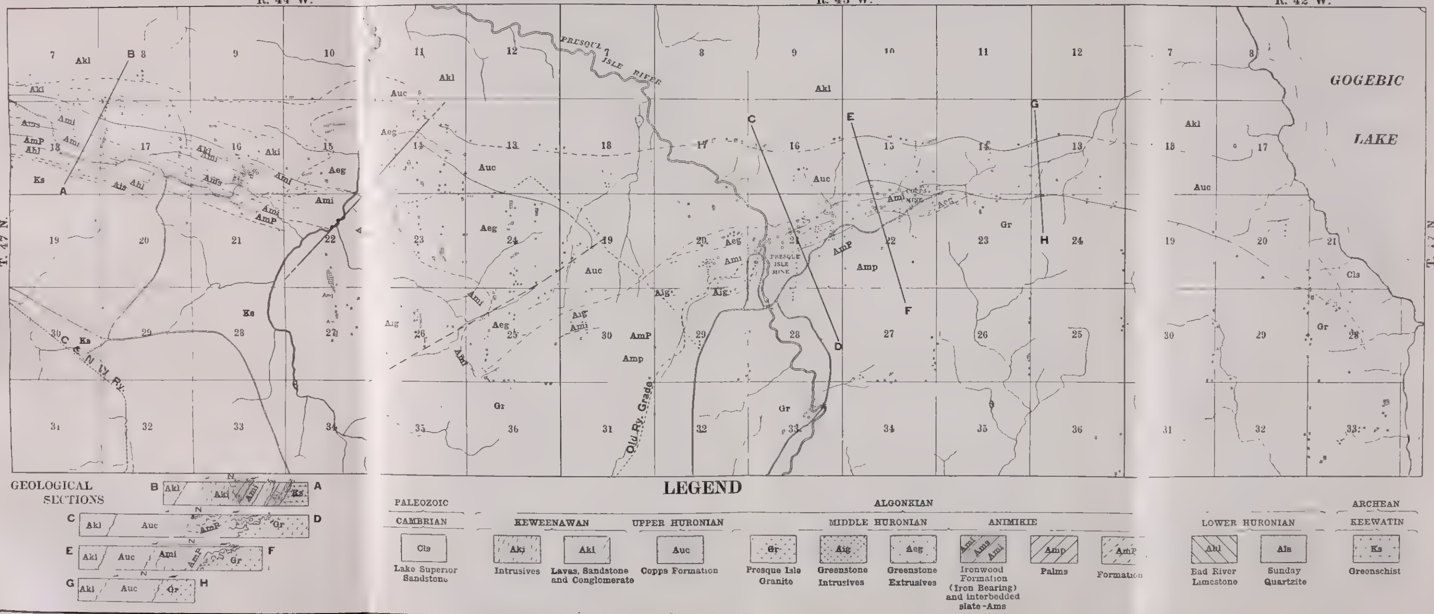
Lithology. The Ironwood formation carries the iron ore bodies of the Gogebic range. In the central and western parts of the district it is made up of the following main varieties of rocks: (1) ferruginous chert, (2) ferruginous slate, (3) slaty and commonly cherty iron carbonate, (4) actinolitic and magnetitic schists, (5) black and gray slate, and (6) iron ore. Concerning the distribution of the above rocks in the formation Van Hise and Leith* summarize as follows: "The iron bearing carbonates are usually found only near the upper part of the formation where they have been protected by the Tyler slate. The ferruginous slates and ferruginous cherts are characteristic of the central iron-producing part of the district, and the actinolitic and magnetitic slates are characteristic of the eastern and western parts of the district. The latter also form a belt 20 to 300 feet wide bordering the Keweenawan rocks on the north. In the intermediate areas there are of course gradations between the ferruginous slates and ferruginous cherts and the actinolitic and magnetitic slates, as there are also gradations between the cherty iron carbonates and the ferruginous slates and ferruginous cherts. Black slates form thin intercalated layers in the iron bearing formations. Quartzite is also found in layers up to 100 feet thick well up from the base of the formation near Sunday Lake."

Interbedded slate and graywacke. With the exception of the increasing importance of interbedded clastic sediments the Ironwood formation east of T 47 N, R 45 W, maintains its general lithologic characteristics. In sections 16, 17, 18, and 21, T 47 N, R 44 W, it is split 200 feet up from the base by a great graywacke-slate member 500 feet thick. This slate is probably continuous with the so-called "secondary slate foot wall" of the Brotherton, Sunday Lake, and Castile mines at Wakefield. The Meteor shaft in section 11 is sunk in this slate and recent diamond drilling in section 12 has encountered the same rock. At the Brotherton and Sunday Lake mines the thickness of this member varies from 40 to 140 feet. At the Castile and Meteor locations and the exploration in section 12, T 47 N, R 45 W, its thickness is unknown. In sections 16 and 17, T 47 N, R 44 W, the

*Monograph 52, U. S. Geological Survey, page 231.

MAP OF THE EAST END OF THE GOGEBIC IRON RANGE, MICHIGAN. Fig. 2 B.

SHOWING OUTCROPS, DRILL HOLES, EXPLORATIONS ETC. BY R. C. ALLEN AND L. P. BARRETT.



slate has been cross sectioned in two places by drilling and the thickness is in the neighborhood of 500 feet. This member of the Ironwood formation is not exposed at the surface.

The extensive explorations made by the Presque Isle Mining Co. has disclosed the character of the Ironwood formation in sections 20, 21, and 22, T 47 N, R 43 W. The formation in this township contains, especially in the upper horizon, lenses and layers of slate, some of whcih are of considerable thickness. Although the problem of the correlation of these members is complicated by folding it is believed that the slates are not continuous. It seems more probable from the available data that they are lenses and are not continuous over any great distance. The slates are not exposed and consequently knowledge of their character is based almost entirely on drill cores. For the most part they are fine grained, gray, green or red and commonly soft but occasionally harder and more quartzose phases are encountered. A noticeable feature is the almost total absence of black slate. No attempt has been made to differentiate on the accompanying map the slate in T 47 N, R 43 W, from the nonclastic portion of the Ironwood formation.

Lithology of the Ironwood formation in T 47 N, R 44 W. The total thickness of the Ironwood formation in sections 16, 17, 18, and 21, T 47 N, R 44 W, is in the neighborhood of 1400 or 1500 feet. This great thickness is due largely to the presence of the 500 feet of graywacke-slate above described. For the purposes of this description the iron bearing rocks below the graywacke-slate will be referred to as the lower member and the iron bearing rocks above the slate as the upper member.

Exposures of the lower member are not plentiful, being limited to three test pits in section 17 and a few outcrops on a low north facing ridge in section 21. All of the exposures are in the horizon immediately above the foot wall quartzite. The rocks on the dump of the pits in section 17 are soft, rich, ferruginous chert and the peculiar semi-detrital material characteristic of the basal horizon of the Ironwood. This detrital rock consists of thin layers in which red and white rounded grains of quartz are embedded in a chert matrix. The detrital grains average about one-sixtieth of an inch in diameter as a rule but occasional pebbles of quartz up to one-half inch in diameter are present. Detrital material is in general subordinate to the nonclastic chert matrix. It may be added that this peculiar basal horizon is characteristic of the Ironwood formation throughout the range.

In section 21 the contact between the Ironwood and Palms formations is marked by a narrow, strongly magnetic field in which the exposures are actinolite-magnetite schists. It is evident from the narrowness of the magnetic field that these rocks are confined to a thin horizon lying directly upon the Palms. According to Van Hise and Irving* these rocks are identical with the actinolite-magnetite schists at Penokee Gap. The explanation of the occurrence of these schists in this locality is in doubt but it is probable that they have been formed through local shearing at the contact between the Palms and Ironwood formations.

The thickness of the lower member is probably in the neighborhood of 200 to 300 feet.

The upper iron bearing member is made up of ferruginous chert, hard jaspilite and amphibole-magnetite slate. An average of 150 analyses of drill cores shows an iron content of 33.48 per cent. Ferruginous cherts are characteristic of the lower-middle horizon. The jasper and amphibole-magnetite slates are characteristic of the upper horizon in contact with intrusive gabbro and associated greenstone sills. Exposures and test pits in the upper horizon are plentiful along the south slope of the high ridge marking the position of the main gabbro mass. The amphibole-magnetite slates at this horizon are characterized by strong to violent magnetism.

The Ironwood formation is in contact with the gabbro on the north for about four miles from the SW$\frac{1}{4}$ of the SE$\frac{1}{4}$ of section 1, T 47 N, R 45 W, east to the SW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 15, T 47 N, R 44 W. From this locality southeast to the great fault in section 25 the overlying rocks are effusive greenstone, agglomerates, and associated basic lavas. It is apparent from magnetic observations that the upper horizon of the Ironwood along the contact with the greenstone effusives carries considerable magnetite although the magnetism is not nearly so strong as that marking the contact of the Ironwood formation and the gabbro. Only two exposures of the Ironwood formation are known from the NE corner of section 22, SE to the NW$\frac{1}{4}$ of section 25, but it is presumed to extend southwest from section 21 to section 25 mainly on the basis of magnetic attraction. There is a group of test pits in hard jasper and amphibole-magnetite chert near the W$\frac{1}{4}$ post of section 23, and a small outcrop of cherty iron carbonate in the southeastern part of the NW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 25.

The Ironwood formation in T 47 N, R 43 W. For the most part the Ironwood formation in this township is made up of ferruginous chert and slate and interbedded lenses of soft gray and green sericitic and chloritic slate. The exposures in section 30, T 47 N, R 43 W, and near the S$\frac{1}{4}$ post in section 25, T 47 N, R 44 W, are amphibole-magnetite chert and schist.

In sections 20, 21, and 22 the iron bearing rocks are ferruginous chert with a subordinate amount of ferruginous slate. An average of 130

*Monograph 19, U. S. Geological Survey, page 243.

analyses from the drill holes in section 20 gives an iron content of 36.87 per cent. This figure is not representative of the formation as a whole as only the richer beds were analyzed.

A noticeable feature of the iron formation in T 47 N, R 43 W, is an abundance of white quartz veins, some of which are large. The unusual number of these veins is in sharp contrast to their general absence in the mines to the west. They were encountered with great frequency in the diamond drilling in adjacent territory and in the Presque Isle mine have rendered worthless in some instances concentrations of hematite that would otherwise be valuable iron ore. It is, therefore, apparent that these quartz veins must be taken into consideration in connection with the ore bearing possibilities of the iron formation in this territory.

On account of the folding and post-Animikie erosion in T 47 N, R 43 W, no accurate estimate of the thickness of the Ironwood formation is possible. There is no reason to believe, however, that, as originally deposited, it is thinner here than elsewhere on the Gogebic range.

Relations of the Ironwood formation to adjacent formations. The Ironwood formation rests conformably upon the Palms quartzite. It is possible that the detrital horizon at its base represents a break in sedimentation. On the other hand it is not inconceivable that this horizon represents merely an abrupt change in conditions from clastic to nonclastic sedimentation. In restricted localities this horizon is conglomeratic. In a test shaft dump near the center of section 21, T 47 N, R 43 W, quartz pebbles up to an inch in diameter may be observed.

The greenstone volcanics in sections 15, 22, 23, and 25, T 47 N, R 44 W, are believed to lie conformably above the Ironwood formation. No contacts are exposed but the field relations are not indicative of any structural break. The exact relationship of the greenstone agglomerates to the iron formation in sections 20 and 21, T 47 N, R 43 W, is unknown. It is probable, however, that they occupy the same stratigraphic position as the greenstones adjacent on the west.

The Copps formation rests unconformably upon the Ironwood formation.

MIDDLE HURONIAN (ANIMIKIE) EXTRUSIVES.

Greenstone Agglomerates and Associated Rocks. Effusive greenstones are found in three localities on the east end of the range, (1) in an area of about 4 sq. miles in the vicinity of sections 23 and 24, T 47 N, R 44 W, (2) in a narrow strip of territory extending east from the center of section 20, T 47 N, R 43 W, to in the vicinity of the E¼ post and, (3) in a small area in the NE¼ of the NE¼ of section 22, and the NW¼ of the NW¼ of section 23, T 47 N, R 43 W.

For a detailed treatment of the lithology of the effusives in these areas the reader is referred to section 3, chapter 8, Monograph 19, U. S. Geological Survey. The description to which we have referred is based on careful microscopic and field study. The effusives are mainly basic volcanic agglomerates and breccias with associated amygdaloidal lavas, tuffs, and some slate and conglomerate. The main area of the greenstone includes, near the base, coarser grained rocks largely of the character of diabase and diorite. These may be intrusive equivalents of some of the flows or they may be later intrusives with no genetic relation to the greenstone effusives. Certain small diabase dikes are without doubt later intrusives, probably Keweenawan. Amygdaloidal lavas are characteristic of the upper horizon of the greenstone immediately underlying the Copps formation, although an occasional bed is found near the center of the greenstone area.

The effusives in section 20, T 47 N, R 43 W, are agglomeratic in all of the exposures. In sections 22 and 23 the greenstone includes both agglomeratic and fine grained basic flows.

The greenstones at locality (1) are apparently superimposed upon the Ironwood formation, perhaps in part interbedded in the upper horizons. At locality (2) the relationship, as previously stated, is not clear. If the greenstone occupies the same stratigraphic position with reference to the Ironwood formation as it appears to occupy farther west, it is probable that they are in the center of a syncline overturned to the south, the north limb of which has been truncated by post-Animikie erosion. With regard to the position of the greenstone in locality (3) nothing definite is known, but the general field relations indicate that these rocks are interbedded with the lower horizons of the Ironwood fromation.

The Copps series is believed to rest unconformably on the greenstone agglomerates. The inference is based on general field relations and the presence of pebbles of the greenstone in the Copps conglomerate. No actual contacts are exposed. Wherever the Copps formation is in juxtaposition to the volcanic greenstone it invariably dips away from it. Volcanic rocks have not been found in the Copps formation.

BASIC INTRUSIVES.

Basic intrusives occur in two main areas, viz, (1) massive diabase in sections 22, 26, and 27, T 47 N, R 44 W, and (2) fine grained greenstone in sections 20, 29, and 30, T 47 N, R 43 W. Aside from these two localities there are many small dikes of diabase which intrude the entire Huronian succession.

We have not examined these greenstones microscopically and shall therefore rely wholly upon the petrographic studies of Van Hise and Irving to which the reader is referred for a detailed discussion*.

Diabase in Sections 22, 26 and 27, T 47 N, R 44 W. Exposures in this locality occupy two high ridges trending north and south. The more prominent one extends from the center of section 27 to about one-quarter of a mile north of the S¼ post of section 22; the other is located in the north central part of section 26. Both hills are characterized by a steep to precipitous west face and a more gentle eastern slope. A noticeable major jointing strikes approximately N-S and dips east. The greater number of exposures exhibited are typical diabase but in places they grade into coarse textured gabbro.

In the west side of the hill in section 26 a narrow belt of banded amphibole-magnetite chert 50 feet thick is exposed. It strikes N 7° W and dips 55° E. The iron formation is underlain by diabase and overlain by fine grained massive greenstone grading upward into diabase but neither the upper nor the lower contact is exposed.

A mile west of this locality a few feet of magnetic slate striking N 20° W and dipping 32° NE is exposed at the base of a prominent westward facing bluff of diabase. The relations indicate clearly that the overlying diabase is an intrusive sill. For the most part the contact between the slate and diabase is parallel to the banding of the formation but at one point a dike of diabase 4 feet wide cuts directly across the bedding. Small fragments of slate up to one foot in diameter are imbedded in the diabase close to the contact. Faulting normal to the plane of the contact has effected small displacements in both rocks. The thickness of the slate is unknown. It is noticeable that the most prominent set of joints in the diabase is parallel in strike and dip to the banding in the slates in section 27 and the amphibole-magnetite chert in section 26. It seems not unlikely in view of the above facts and the general topographic expression of the hills that the diabase is in the form of sills of great thickness intruded in the Huronian series.

In describing this greenstone Van Hise correlated the fine grained amygdaloidal greenstones in the northern half of section 15 with the diabase to the south, but we would favor including the amygdaloidal greenstones in the overlying greenstone effusives. Their position seems to warrant direct correlation with the upper horizon of amygdaloidal lava.

Greenstone in Sections 20, 29, 30, T 47 N, R 43 W. Greenstone is exposed in a high ridge south of the iron formation in the southeast half of section 20, in a hill in the northwest part of section 29, and in a low ridge extending about east and west through the center of the

*Monograph 19, U. S. Geological Survey.

NW¼ of section 30. Van Hise* describes these rocks as follows: "Petrographically this rock has all the characteristics of a surface flow. It is a much altered augite-porphyrite. It varies a good deal in coarseness of grain and degree of alteration, but the original minerals are found with sufficient frequency and the secondary minerals are so uniformly the same that there is every reason to believe that detached exposures are parts of a continuous belt. The original minerals are menaccanite, plagioclase, and augite, this being the order of crystallization. The secondary ones are kaolin, chlorite, epidote, leucoxine, and smaragdite." Van Hise also noted a mineralogical similarity between the augite porphyrite and the diabase in sections 26 and 27, T 47 N, R 44 W. "In original minerals contained in secondary products the augite-porphyrites are almost precisely like the diabases of the first division. The similarity is so remarkable as to make it probable that the rocks of the two divisions are, or once were, connected. The likeness is further reinforced by the correspondence of the double angles of the feldspar as measured by Pumpelly's method." Macroscopically they differ. The augite-porphyrites are usually fine grained while the diabase is characterized by coarse crystallization.

Van Hise regards the augite-porphyrites as probably interbedded surface flows. The workings of the Presque Isle mine together with the diamond drilling show conclusively that the greenstone is intrusive in the iron formation at that locality. The iron formation dips south and the greenstone cuts directly across the bedding. The plane of contact between the greenstone and iron formation is nearly vertical.

Rocks very similar in appearance to those just described occur on a small knoll just west of the group of old test pits and trenches in the S½ of the NE¼ of section 21. The relations of this greenstone with adjacent iron formation and quartzite are unknown but are not presumed to be different from the relations exhibited at the Presque Isle mine.

PRESQUE ISLE GRANITE.

Location and Extent. The Presque Isle granite is so named because of its typical exposures along the Presque Isle River in the south half of T 47 N, R 43 W. It includes the rocks described by Van Hise and Irving as constituting the "Eastern Laurentian Granite area."† It is probable that the Presque Isle granite is to be correlated directly with the great granitic intrusives that cover a large area southward in Michigan and Northern Wisconsin, possibly including the granite of the Florence and Menominee districts heretofore doubtfully correlated

*Monograph 19, U. S. Geological Survey, pp. 414-15.
†Monograph 19, U. S. Geological Survey.

with the Keweenawan. (See discussion of the Marenisco, Turtle, and Manitowish ranges and the Vieux Desert-Conover district).

Lithology. The term granite is here used in a loose sense to cover rocks that are predominantly acid granites, but which include here and there rocks of more basic types not excluding syenite and diorite. The basic varieties are possibly differentiation products of a normally acid magma although their predominance near the contact with the Huronian sediments may perhaps be accounted for on the theory that the marginal tendency towards basicity is an endomorphic effect of the intrusion of granite into the Animikie series.

Van Hise summarizes the description of the Eastern granite as follows: "In all essential respects the massive rocks here contained are like those found in the granite areas to the westward. The phases here included run from typical syenites to typical quartzose granites. Usually in them, as in the previous areas, an alkaline feldspar, occurring largely in idiomorphic forms, is the chief constituent. In a few of the exposures quartz is as abundant as the feldspar. In some cases in this area the decomposition of the feldspar has gone far. Aside from the quartz and feldspar, hornblende and chlorite, as in the Central granite, are the only important minerals, and very frequently the chlorite, as in it, has resulted from the alteration of the hornblende or the decomposition of the feldspar. The typical syenite exposures are more common than in the other two granite areas." The Presque Isle granite is mainly massive but marked gneissosity is not an uncommon feature. In general the rocks are light gray to white in color and acid in composition. They are very uneven grained and cut by innumerable pegmatite dikes. Along the road leading from Marenisco to the Presque Isle mine predominant white varieties give the rock the appearance of massive white quartz or dolomite when seen from a distance. In T 47 N, R 42 W, there are limited areas of red granite.

Relation of Presque Isle Granite to Middle Huronian (Animikie) Formations. The inference that the Presque Isle granite is intrusive into the Animikie formations rests on the following evidence:

1. The exposures of the Palms formation show a gradual transition, in proportion as they approach the granite, to micaceous and hornblendic schists and gneisses with accompanying obliteration of clastic textures.

2. The Palms and Ironwood formations are characterized by abundant quartz veins and the Palms formation by veins of aplite and pegmatite which become increasingly prominent toward the granite.

3. The Ironwood formation becomes amphibolitic, magnetitic and schistose in section 25, T 47 N, R 44 W and section 30, T 47 N, R 43

W, where closely approached by diorite and hornblende syenite which is correlated with the Presque Isle intrusives.

4. At this latter locality the Palms formation is absent and the amphibole-magnetite slate of the Ironwood is separated by only a short distance from exposures of diorite and hornblende syenite believed to belong to the Presque Isle granite.

The above remarks may be illustrated by reference to certain localities. The exposures showing the metamorphism of the Palms to best advantage are in sections 21 and 28, T 47 N, R 43 W, earlier described. In no other locality are exposures sufficiently abundant to permit observation of the gradual change from graywacke and slate to crystalline schists. Mention will be made here of a few other localities where the same phenomenon may be less satisfactorily observed.

Exposures of slightly altered phases of the Palms are found near the center, and at the E$\frac{1}{4}$ post of section 29, and at the bridge where the township road crosses the Presque Isle River in section 28. The clastic texture is usually present in some of the coarser grained bands, but in the finer grained layers no sedimentary textures remain. In the exposures in section 29 small needles and fibres of green hornblende are visible under the microscope although not usually determinable in hand specimen. The outcrop near the east $\frac{1}{4}$ post of section 29 is cut by quartz veins, some of which are feldspathic. A short distance south the rocks are fine grained hornblende-mica gneisses cut by bands and dikes of granite and pegmatite. From this point south to the granite exposures are numerous; the hornblende gneisses become gradually coarser grained and the granitic material increases in amount until finally the rock is contorted and banded gneiss made up of alternate layers of granite and hornblende schist, cut indifferently by dikes of aplite and pegmatite. Nowhere is it possible to draw a sharp boundary between the granite and the Palms formation. The base of the latter is doubtless involved in the former and can only be represented on the map by a transitional zone.

The unusual abundance of quartz veins in the Ironwood formation in T 47 N, R 43 W, has already been referred to and merely need be recalled at this point. Although no trace of feldspathic material was noted in the quartz veins in the Presque Isle mine the presence of these veins in unusual numbers in this particular part of the range is significant. If correctly interpreted as originating from hot magmatic waters derived from the Presque Isle intrusive, the quartz veins are the only direct metamorphic effect of this granite on the iron formation in sections 20, 21 and 22. The explanation of the absence of marked metamorphism of the iron formation here probably lies in the competency of the massive upper quartzite member of the Palms through which the granite magma was not able to penetrate.

Farther west in the SE$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 30, and in the SW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 25, there are exposures of amphibole-magnetite slate and chert. In section 25 the iron formation is overlain by greenstone agglomerate and is only about 50 feet north of exposures of diorite and hornblende syenite. The total thickness of iron formation cannot be more than 150 to 200 feet. The outcrops of amphibole-magnetite schist and chert in section 30 lie south of a low ridge of augite-porphyrite. They are larger and more extensive than the outcrops in section 25. Four hundred paces south of the iron formation, diorite similar to the exposure in the south part of section 23 is encountered. An intervening test pit is ledged in fine grained hornblende schist similar macroscopically and microscopically to metamorphic phases of the Palms.

It should be stated that there is no absolute proof that the iron formation in section 30 is continuous as a part of the main belt in section 20, although such connection is plainly indicated. The apparent discontinuity is the result of folding and displacement which will be discussed later.

The same statement applies to the outcrops in section 25, and in fact it seems possible from consideration of the magnetic observations in the intervening territory that igneous intrusives may have eaten their way up through the entire iron bearing series between the exposures in section 25 and those in section 30.

There can be little doubt that the diorite and hornblende syenite are the rocks responsible for the metamorphism of the iron formation at both localities. As to whether they should be correlated with the Presque Isle intrusives is not so clear. Macroscopically the diroite and syenite differ from the other basic rocks in the east end of the range in being lighter colored and in many places banded or gneissose. The exposures are uneven grained and vary rapidly in composition, becoming in places gradationally more acid and including phases of hornblende syenite. Some of the hornblende syenite is porphyritic in texture; phenocrysts of light pinkish and gray orthoclase up to one-half inch in diameter are imbedded in a fine grained matrix of hornblende and feldspar. The more basic varieties are commonly badly altered and when examined microscopically are found to be made up of ragged green hornblende and a badly altered basic feldspar. The alteration products are gray saussurite, epidote, zoisite, and sericite. Leucoxine and pyrite are found in small quantities. A noticeable feature is the general absence of magnetite which is found in all the other basic rocks in sufficient quantity to affect the dip needle.

It is not possible to establish a direct areal connection of these basic rocks with the main mass of granite to the south but in view of their similarity in structural features and sudden compositional and textural changes it is regarded as likely that these rocks are a part of the main intrusive granite. The basic types may be well interpreted as a product of differentiation or if, as seems possible, the Presque Isle intrusives have in this vicinity eaten their way up through the underlying Palms and in section 25 through the greater portion of the Ironwood, the basicity of the adjacent rocks may be a direct result of the absorption and assimilation of the Animikie sediments.

Relation of the Presque Isle Granite to the Copps Formation. The Copps formation rests unconformably upon the Presque Isle granite. The contact is marked by a great conglomerate carrying boulders and pebbles of the granite.

Upper Huronian Series.

COPPS FORMATION.

Location. The Copps formation is the name proposed for the rocks which occupy most of the area which is mapped and described in Monograph 19, U. S. Geological Survey as "Ferruginous Slates of the Eastern Area."

The most westerly of the exposures which can be correlated with the Copps formation with certainty are those of ferruginous graywacke in section 14, T 47 N, R 44 W. A mile and a half farther west in the SW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 15. there is a small group of test pits ledged in black slate and graywacke. The dumps of these pits include also a small amount of ferruginous chert and jasper. If these rocks are referable to the Copps, and this seems not unlikely in view of their position and lithologic character, this formation extends as far east as section 18, T 47 N, R 44 W, where it occupies the valley lying between the Keweenawan lavas on the north and the high gabbro ridge on the south. This valley gradually narrows toward the west and disappears in section 6, T 47 N, R 45 W, where the gabbro is apparently in direct contact with the Keweenawan amygdaloidal trap. The only evidence of the character of the rocks occupying this depression is afforded by the pits in section 15 and the occurrence of a strong magnetic belt at the north base of the gabbro hill in section 8, T 47 N, R 44 W.

The east limit of the Copps formation is in section 28. T 47 N, R 42 W, where it is unconformably overlapped by flat lying red sandstones of Cambrian (?) age.

Lithology. The Copps formation is essentially graywacke slate, highly ferruginous in its western and central parts but becoming decreasingly ferriferous eastward from section 22, T 47 N, R 43 W. Bands of chert and jasper are characteristic of the lower horizons. The base of the series wherever exposed is marked by a well defined conglomerate.

The iron bearing minerals form a cement in which the fragmental grains are imbedded. In the westerly exposures iron oxide, largely hematite but including considerable magnetite, is predominant. In sections 16, 17 and 20 the oxide and carbonate of iron are both present and east of section 16 the iron mineral is largely siderite. According to Van Hise* the relations between the iron oxide and iron carbonate indicate that the former is derived from the latter. Microscopic study reveals the presence of iron carbonate in all stages of alteration to iron oxide.

The lower horizon of the Copps is a well defined basal conglomerate. From section 23, T 47 N, R 43 W, east to the extremity of the range the Copps conglomerate is in contact with the Presque Isle granite. It is here composed of granite boulders and pebbles, ranging up to four or five feet in diameter, imbedded in a matrix of arkose which includes also a considerable quantity of iron carbonate. In addition to the granite boulders are a few pebbles of greenstone, quartz, chert, and more rarely quartzite and jasper. Exposures of the granite conglommerate are found in section 28, T 47 N, R 42 W, and in sections 23 and 24, T 47 N, R 43 W.

North of the old Copps mine near the southeast corner of section 15, T 47 N, R 43 W, the Copps formation truncates the Animikie formation. Here the granite pebbles have entirely disappeared giving place to small fragments of chert, quartz, and occasionally quartzite imbedded in a matrix consisting of smaller grains of quartz, chert, feldspar, and a large amount of iron carbonate.

The conglomerate horizon was cut by a drill hole in the northeast part of section 21 and is also exposed in test pits a short distance north of the center of this section. In these localities the conglomerate contains pebbles of quartz, jasper, quartzite, and chert imbedded in a graywacke matrix which includes a small amount of iron oxide.

West of section 21 conglomerates are found in test pits in section 19, T 47 N, R 43 W, in section 14, T 47 N, R 44 W, and in fact, according to J. M. Longyear, Jr., "all along the north and east edges of the greenstone area" in sections 13, 14, 19 and 24, T 47 N, R 44 W[1].

It is not possible to work out in any detail from available data a definite succession of dissimilar members for the Copps formation but the following probably expresses in a very general way the succession in the territory from section 13 to section 17, T 47 N, R 43 W. East

*Monograph 19, U. S. Geological Survey, pp. 392-3.
[1]A thesis on the geology of part of the Gogebic range, Harvard University, 1915. (unpublished.)

of section 13 and west of section 17 information is too meager to justify even general statements.

The base of the formation is conglomerate which grades up into hard graywacke carrying layers of chert and, in the western part of the formation, narrow seams of jasper. The cherty bands near the base of the formation are persistent everywhere. An interesting feature is the presence in the chert bands of considerable detrital material and even in the associated clastic bands there is a subordinate amount of interstitial chert.

In the eastern part of section 15 and the western part of section 14 the ferruginous graywacke and chert are sharply overlain by a thin belt of black slate. Whether this member is persistent or is merely a local feature can not be determined. The black slate grades upward into coarser grained graywacke characterized by a considerable content of magnetite. This member can be traced magnetically and by outcrops from section 19, T 47 N, R 42 W, to section 20, T 47 N, R 43 W. Associated with the graywacke are slates and a few beds of lighter colored feldspathic quartzites. The magnetic graywacke is composed mainly of rounded grains of quartz and feldspar, the latter including orthoclase, plagioclase, and microcline. The interstitial material comprises magnetite, hematite, carbonate, sericite, and chlorite. Magnetite occurs also in a later second generation of large well formed crystals which contain inclusions of the other minerals.

Above the magnetic graywacke are graywacke and slate, more or less ferruginous, containing locally considerable magnetite. In this connection it may be said that the entire Copps formation west of T 47 N, R 42 W, is weakly magnetic. The rocks termed here magnetic graywacke contain important quantities of magnetite. The other graywackes and associated rocks present no unusual petrographic features.

In the central part of the Copps formation the highest member is a soft slate. Its color is dark gray or grayish green excepting only a red phase at the top which grades downward irregularly into the darker colored facies.

In T 47 N, R 42 W, exposures of the Copps formation are confined to the lower horizons. The cherty bands characteristic of the member immediately above the basal conglomerate are present and the overlying rocks, insofar as it is possible to determine, are largely soft gray and green choloritic and sericitic slates. Iron carbonate, and to a limited extent iron oxide, are present but the relative importance of these minerals in the general make up of the rock has diminished when compared with their abundance farther west.

In the western exposures in T 47 N, R 44 W, the rocks are rather coarse grained and highly ferruginous carrying bands and layers of red chert, jaspilite and slate. The iron is almost entirely in the form of hematite with subordinate magnetite. The clastic grains include quartz, feldspar, red chert, and rarely jasper.

The width of the Copps formation lessens rapidly going west from section 19, T 47 N, R 43 W, and in section 14, T 47 N, R 44 W, has narrowed to about 300 paces. This is believed to be due to erosion prior to the deposition of the Keweenawan series. This conclusion is strengthened by the fact that the ferruginous graywackes and associated cherty material characteristic of the lower horizons farther east are in section 14 in contact with the overlying Keweenawan lavas.

The outcrops of ferruginous graywacke in the southeast part of section 19 and the north half of section 30, T 47 N, R 43 W, are almost identical with the exposures in section 14, T 47 N, R 44 W, and require no special description.

Thickness of the Copps Formation. The Copps formation is one of considerable thickness. Throughout the greater part of its extent it has a surface width averaging well over a half mile. Assuming a northerly dip of 65° in sections 13, 14 and 15, T 47 N, R 43 W, the thickness is not less than 2300 feet. It is possible that some of the beds are repeated by close folding but the figure given is believed to be slightly if any in excess of the actual thickness of the formation.

Relations to Adjacent Formations. The Copps formation rests unconformably above the Presque Isle granite. The relationship is clearly indicated by the prominent granite conglomerate marking their contact. It is separated from the underlying Animikie formations by an unconformity of great structural and erosional magnitude. This conclusion rests on the following evidence:

1. The bottom horizon of the Copps formation is a true basal conglomerate containing fragments of the underlying Palms and Ironwood formations.

2. The Presque Isle granite intrudes the Palms and Ironwood formations but yields boulders and matrix to the basal conglomerate of the Copps formation.

3. The Copps formation is in great structural discordance with the Animikie group.

4. The areal relationships are those of unconformity.

5. Volcanic rocks are characteristic of the Animikie but are apparently entirely absent in the overlying Copps formation.

The structural and areal relationships are shown on the accompanying map and structure sections, (fig. 2) and are discussed in another place.

Keweenawan Series.

It is not intended to discuss the Keweenawan series except with regard to its relations to the subjacent Huronian group. The great Keweenawan series of lavas, sandstone and conglomerate limits the Huronian series on the north throughout the entire length of the Gogebic iron range. In addition to the overlying lavas and associated sandstones and conglomerates the Keweenawan series also includes the diabase dikes which cut the Huronian rocks and have played such an important part in the localization of the iron ore bodies. The Keweenawan is also believed to include the gabbro intrusive in the east part of T 47 N, R 44 W.

Relation of the Keweenawan to Adjacent Formations. In the east end of the range the Keweenawan series is in contact only with the Copps formation which it overlies unconformably. This relationship is clearly indicated in the exposures and test pits 450 paces west of the E¼ post of section 15. The base of the Keweenawan in this vicinity is a partially indurated sandstone 50 to 75 feet thick marked by a strong basal conglomerate. The subjacent rocks of the Copps series are soft red slate and the conglomerate immediately above them contains abundant pebbles of this red slate and in addition pebbles of vein quartz, quartzite, graywacke, jasper, chert and iron ore derived from the various formations of the Huronian group.

Keweenawan (?) Gabbro in T 47 N, R 44 W. Reference has been made in connection with the discussion of the Ironwood formation in T 47 N, R 44 W, to the high ridge of gabbro extending from section 1, T 47 N, R 45 W, southeast to section 15, T 47 N, R 44 W. This ridge lies north of the Ironwood formation and is parallel to it. The rock varies from a coarse grained gabbro to fine grained diabase. Close to the contact with the iron formation the greenstone is aphanitic. The gabbro is best exposed in the southwest part of section 8 and the northwest part of section 17, although outcrops are plentiful in all parts of the ridge. The outcrops in sections 8 and 17 furnish the most favorable locality for observation of a well developed system of joints. The most prominent set strikes about east and west and dips south. A less marked set of joints, normal to the first, dips east.

The gabbro is in contact with the Ironwood formation on the south; on the east it is limited by the greenstone agglomerates and effusive lavas. North of section 15 the gabbro is separated from the Keweenawan by a valley about one-half mile wide. This valley narrows toward the west and in section 1, T 47 N, R 45 W, the gabbro is apparently in direct contact with the trap. The gabbro thins rapidly westward and does not appear west of the NE¼ of the SE¼ of section

1. From section 1, T 47 N, R 45 W, to Sunday Lake the Keweenawan overlies the Ironwood formation.

The exact relationship of the gabbro to adjacent rocks is not clear except in the case of the iron formation; actual contacts are nowhere exposed. The Ironwood formation adjacent to the gabbro is everywhere characterized by highly metamorphic facies including amphibole-magnetite schist and slate and hard jaspilite, and this fact together with the occurrence of intrusive sills of fine grained dolorite in its upper horizon is strong evidence that the gabbro intrudes the Ironwood formation. The exact form of intrusion of the gabbro is not known. It may be either an immense dike or a sill. A prominent jointing or sheeting dipping southward at 65° in a plane approximately parallel to the northern and southern bases of the ridge suggest that this plane is also probably parallel to the opposite surfaces of the intrusives, in which case the intrusive is in the form of a dike dipping southward and inclined about 55° to the plane of the bedding in the iron formation.

In section 1, T 47 N, R 45 W, outcrops of gabbro are found only 75 paces south of the Keweenawan lavas. There is no evidence in the trap outcrops of contact metamorphic action and it is not possible to determine the relationship between them and the gabbro.

To summarize,—the gabbro intrudes the Ironwood formation. There is indirect evidence that it intrudes the rocks (Copps formation?) occupying the valley separating the gabbro from the Keweenawan in sections 7, 8, 15 and 16, T 47 N, R 44 W. There is no evidence that gabbro intrudes the Keweenawan.

Van Hise makes only slight reference to the gabbro intrusive but apparently correlates it with the Keweenawan.

Structure of the Gogebic Range east of Wakefield.

From T 44 N, R 6 W, Wisconsin, eastward to the center of T 47 N, R 46 W, Michigan, the Gogebic range is a steeply northward dipping monocline, but east of the Black River the structure is locally complicated.

From the vicinity of the Eureka mine east to the Castile mine the Lower Huronian and Animikie (Middle Huronian) formations are folded, faulted, and intruded by dikes and irregular masses of greenstones. The most noticeable feature is the great thrust fault at Wakefield. With the exception of the general northward tilting the folding and faulting of the Huronian rocks took place prior to Keweenawan time and after the deposition and induration of the Animikie (Middle Huronian) series.

From the Castile mine eastward to section 22, T 47 N, R 44 W, the structure of the range is, so far as known, a simple northward dipping monocline similar to that west of the Black River. The Lower Huronian and Animikie (Middle Huronian) series dip north at angles varying from 35° to 65°. The structure is illustrated by section AA accompanying the general map. In section 22, T 47 N, R 44 W, and eastward the structure again becomes complicated and except where diamond drill holes have supplied the data it is not possible to work it out in detail. The structural problem is complicated by great intrusions of granite and greenstone and by immense masses of basic volcanic material. In fact the igneous activity of Animikie time in the east end of the range is probably closely related to the exceptional local deformation of the pre-Copps rocks.

From section 22, T 47 N, R 44 W, eastward to section 20, T 47 N, R 43 W, little is known of the details of the structure. Exposures of igneous rocks are plentiful but the sedimentary rocks are mainly drift covered. The iron formation can be traced magnetically wherever the magnetism has developed in sufficient strength so that the iron formation can be clearly differentiated from the associated greenstones which are nearly everywhere weakly magnetic. In sections 20, 21, and 22 it is possible to work out the structure in some detail.

Geologic structural sections have been drawn only in localities where surface data is supplemented by diamond drilling or underground exploration.

Structure of the Keweenawan series. The Keweenawan series has an approximate eastward strike and uniform northward dip. Superimposed on the northward dipping monocline are gentle cross folds which are indicated by the gently sinuous character of the Copps-Keweenawan line of contact in sections 13 to 17, T 47 N, R 43 W. A cross anticline in the vicinity of sections 14 and 15, T 47 N, R 44 W, is particularly well marked. It is possible that the Keweenawan is cut by the cross fault in section 14, T 47 N, R 44 W, which has apparently produced a horizontal misplacement of about 1500 feet in the underlying Copps formation and Animikie volcanics.

Structure of the Copps Formation. The trend of the Copps formation is about parallel to the Keweenawan and its dip is northward. Southward dips are confined, so far as known, to the secondary structure, i. e. schistosity or slaty cleavage, while the bedding invariably dips northward so far as observed. The bands of chert and jasper near the base of the formation dip north and northward dips are exhibited wherever bedding is recognizable in the slates and graywackes. In the slate exposures in the SE$\frac{1}{4}$ of the SE$\frac{1}{4}$ of section 15, T 47 N, R 43 W, the cleavage dips south at angles varying from 45° to 80°, but the bedding is nearly vertical or steeply inclined to the north. This is the only locality where the dips of bedding and shistosity are opposed in the same exposure. An exception to the general northward dip of the Copps occurs in the exposures of ferruginous graywacke in the southwest part of section 19 and the NW$\frac{1}{4}$ of section 30, T 47 N, R 43 W. These rocks are mainly massive and exhibit neither bedding nor schistosity except in an outcrop near the southwest corner of section 19 which contains narrow bands of chert striking northeast and dipping southeast. The occurrence of the Copps formation in this locality is of considerable structural significance. The Animikie rocks are here believed to be compressed into an overturned syncline with axial plane striking NE-SW and dipping northwest. It is probable that this fold has passed into a thrust fault, the plane of which is approximately parallel to the axial plane of the syncline. While the position of the ferruginous graywacke here indicates that the graywacke is younger than the Animikie volcanics and iron formation it may be equivalent to the upper horizon of the Ironwood or the lower part of the Tyler formation. If any part of the Tyler formation is preserved on the east end of the range the remnant should be looked for in synclines such as this. There is considerable lithologic dissimilarity between the ferruginous graywacke at this locality and the Tyler sediments, while on the other hand it is identical in appearance and composition with phases of the Copps rocks. It is of course possible that the exceptional conditions which prevail in this part of the range may account for the deposition of material entirely dissimilar to that elsewhere simultaneously laid down.

The determination of the time at which the deformation and folding in this locality took place is directly related to the problem of the age of the ferruginous graywacke. There are three possibilities. (1) If the ferruginous graywacke is equivalent in time to the Tyler or to the Ironwood formation the deformation is probably post-Animikie and pre-Copps because there is no evidence elsewhere of any pre-Keweenawan folding in the Copps. (2) Assuming that these rocks are part of the Copps formation it is possible that the folding may have taken place prior to the deposition of the Copps and to have resulted in the formation of a basin or depression which was later filled by the post-Animikie sediments. (3) Finally, if the ferruginous graywacke belongs to the Copps and has been itself affected by the folding, the age of the disturbance is post-Copps and probably Keweenawan.

Structure of the Middle Huronian Series (Animikie). It is impossible to obtain sufficient information on which to work out the detailed structure of the Animikie rocks except in the vicinity of sections 21 and 22, T 47 N, R 43 W. From the west line of section 21 east to section 22, T 47 N, R 44 W, the available data warrants nothing beyond a general idea of the gross structure.

The structural conditions in the east part of T 47 N, R 43 W, are exhibited by the geologic sections (Fig. 2) which are based to a great extent upon the drill records of the Presque Isle Mining Company. The data for structural sections here are unusually ample because of the large amount of drilling and test pitting which has been executed, fortunately in a most critical area from the structural point of view.

The chief fact brought out by the structure is the pre-Copps folding of the Middle Huronian (Animikie) and the truncation of these folds by the Copps formation. East of the center of the NW¼ of section 21 the Copps formation is first in contact with the iron formation, then the Palms quartzite and finally, in the northeast part of the section, again with the Ironwood formation. In the NE¼ of the section a drill hole pointed south entered the Copps formation, passed through its basal conglomerate and penetrated the Palms quartzite without encountering the Ironwood formation. These relations indicate that the Middle Huronian (Animikie) sediments were deposited, indurated, folded, uplifted, eroded, and depressed prior to the deposition of the Copps rocks.

The Middle Huronian (Animikie) series in sections 20, 21, and 22 forms two major synclines, one pitching east and the other west from the crest of an anticline near the center of section 21. The eastward pitching trough is divided by a secondary anticline into two sub-troughs so that the iron formation in the west half of section 21 occurs in two parallel belts which, however, merge into the main single belt in the major syncline in the adjoining section to the east. Details of the structure of the west syncline are not so well known nor does the drilling define the limits or depth of the trough except on the east side of the Presque Isle river. There is some evidence that this trough is broken by cross faulting at the approximate location of the Presque Isle river. The drilling just east of the river indicates a relatively shallow syncline but a short distance west at the Presque Isle mine drill holes to a depth of 850 feet have failed to reach the bottom of the trough. The sudden termination of the greenstone belts north and south of the iron formation is also suggestive of faulting. If there is a fault at this locality it is evident that the rocks west of the river are on the down thrown side.

Nothing is known concerning the attitude of the wide belt of iron formation continuing east through section 20 except that the rocks along the north border dip south. The iron formation in the Presque Isle mine and in the old exploration in the NW¼ of the SW¼ of section 20 dips south.

The stratigraphic position of the greenstone agglomerate in section 20 with reference to the Ironwood formation is uncertain. The plane of schistosity in the greenstone dips south parallel to the bedding in the adjacent iron bearing rocks. If the greenstone is stratigraphically above the Ironwood formation as in T 47 N, R 44 W, the volcanics probably occupy the center of an overturned syncline whose axial plane dips south.

It has been said that little is known regarding the structure of section 20 westward to section 22, T 47 N, R 44 W. The following is merely a statement of known facts of structure with such interpretations as seem best fitted to the facts.

The prominent feature of this territory is the great belt of greenstone agglomerate and other extrusives in the east part of T 47 N, R 44 W, and the occurrence of thick diabase sills in sections 26 and 27 of the same township. The relations and structure of the diabase sills have already been discussed. The greenstone agglomerates are in general massive in structure, less commonly schistose. Structural problems in a volcanic formation such as this are hopeless of solution because it is not possible to identify everywhere any of the flows or ash beds which might, if continuous, serve as horizon markers. Detailed petrographic and field study of the greenstones might throw some light on structure, but the chances are that even this would be of slight assistance.

Information regarding the Animikie sediments is also meager. There are no rocks susceptible of correlation with the Palms east of section 22 in T 47 N, R 44 W, and the iron formation is exposed only at wide intervals.

The definite magnetic line immediately south of the greenstone volcanics indicates that the Ironwood formation is continuous from section 22, T 47 N, R 44 W, southeast to the exposure of cherty iron carbonate in the northwest part of section 25, although actual exposures in the intervening territory are found only near the W$\frac{1}{4}$ post of section 23.

Reference has been made to the amphibole magnetite chert and slate associated with the diabase in sections 26 and 27. If these rocks are part of the Ironwood it is evident that this formation is distributed here over a surface width of about a mile, this being accounted for by the occurrence within the formation of the great diabase sills possibly combined with a flattenting of the dip.

The general strike of the iron formation west of the agglomeratic greenstone is southeast. An exception is the exposure in the northwest part of section 25 in which the strike is slightly east of north. The strike of the iron formation belt east of the greenstone in this territory is NE. The most westerly outcrop of iron formation is in the south part of section 25, T 47 N, R 44 W. The magnetic attractions in the south half of section 26 are probably caused by iron formation directly connected with the exposure in section 25.

The difference in strike of the iron formation east and west of the greenstone extrusives is one of the chief structural features in this part of the range. The question at once arises, (1) are the two belts of iron formation one and the same formation or (2) if not now actually connected were they originally deposited as a continuous formation? The evidence on this point seems conclusive. It has been shown that the iron formation in section 21 overlies rocks which are identical in succession and lithologic features with the type exposures of the Palms formation in the central part of the range. The structure in sections 25 and 26 is an overturned fold, the western limb of which has been faulted and thrust eastward and northward above the lower or western limb. There is considerable field evidence in favor of this interpretation (1) in the attitude of the iron formation and greenstone in section 25, (2) the absence of diabase south of the fault line, (3) the location of the magnetic attractions in section 25 and (4) finally in the fact that the indicated fault line follows low ground in both sections. For the most part the above facts show clearly on the map.

A. CHARACTERISTIC EXPOSURES OF PRESQUE ISLE GRANITE IN T. 47 N., R. 43 W.

B. CHARACTERISTIC TOPOGRAPHY OF THE GREENSTONES IN T. 47 N., R. 44 W.

A. ALLIGATOR POINT. LOOKING NORTH FROM SOUTH END OF LAKE GOGEBIC.

B. FALLS ON THE MIDDLE BRANCH OF THE ONTONAGON RIVER, SECTION 32, T. 46 N., R. 41 W., SHOWING JOINTING IN AMYGDALOIDAL GREENSTONE.

CHAPTER IV.

GEOLOGY OF THE MARENISCO RANGE.

R. C. ALLEN AND L. P. BARRETT.

INTRODUCTORY STATEMENT.

The Marenisco Range extends from the northwest corner of T 46 N, R 41 W, Michigan, where it is overlapped by the Keweenawan Series of the South Trap Range, southwestward through Marenisco to T 44 N, R 2 E, Wisconsin, and an unknown distance beyond. It was prospected for iron ore in the 80's near Gogebic Lake in Michigan and in the vicinity of Long and Pine lakes in Wisconsin. At the latter locality the village of Magnetic Center was laid out at the north end of Pine Lake but all traces of it have long since disappeared. Among the early explorers this range was known as the South Range but few today recall its existence.

Only about a half dozen outcrops are known on this range from the vicinity of Marenisco southwestward. In the opposite direction there are a considerable number of exposures but these alone furnish an insufficient basis for geologic mapping. The range is characterized by a strong to violent magnetism which furnishes a ready means and, for the greater part of its extent, the only means of determining its position. That this strong magnetism attracted the early explorers is evidenced by traces of their prospects in the most violently magnetic localities. Fragments of diamond drill cores properly arranged in core trays, were found on the site of the Magnetic Center exploration in a dense forest of hardwood and hemlock in the SW¼ of NE¼, section 28, T 44 N, R 3 E, Wisconsin. These cores furnish the only direct evidence of the nature of the magnetic rock southwest of Marenisco. Although there are many pits and an old shaft in this vicinity there is no evidence that bed rock was opened in any of them. In T 46 N, R 42 W, Michigan, outcrops are more abundant, and in this locality only is it possible to work out a definite succession. Whether the succession here is representative of the range as a whole can not be determined.

Succession on the Marenisco Range. In T 46 N, R 42 W, Michigan.

Keweenawan ?		Diabase.
	Igneous contact	
Huronian	Middle Huronian (Animikie)	Intrusive granite (Presque Isle) Intrusive greenstone Slate Extrusive lavas Iron formation Quartzite and graywacke
	Unconformity	
Archean	Northern area.	Granite and greenstone.
	Southern area.	Mica schist, greenschist and amphibolite. (May be Huronian)

ARCHEAN SYSTEM.

NORTHERN AREA.

The Marenisco range is separated from the Gogebic range to the north by a territory from three to twelve miles wide, underlain for the most part by granitic rocks but including subordinate areas of greenschist. The granite in this area was formerly considered as entirely Laurentian but, as has been shown in the discussion of the east end of the Gogebic range, there is ample evidence that, in part at least, it is intrusive into the Middle Huronian. On the other hand, the relations between the Huronian rocks and the granites and greenschists throughout the major part of the Gogebic range clearly indicate the Archean age of the latter.

On the basis of present knowledge it is not possible to differentiate the granites representing the two or more different periods of intrusion except in limited localities where the relations to adjacent Huronian rocks are exhibited. The facts, however, seem to warrant the general statement that the granite from about the vicinity of the Little Presque Isle river east to Lake Gogebic is preponderantly Middle Huronian.

In section 4, T 46 N, R 42 W, the northern granite intrudes the Middle Huronian slates. Elsewhere the relations between the northern granite and the Huronian sediments may only be inferred.

SOUTHERN AREA.

Location and General Statement. The Marenisco range is separated from the Turtle range by a non-magnetic area two to seven miles wide. In this territory, in sections 4 and 9, T 43 N, R 3 E Wisconsin, there are several outcrops of granite gneiss and hornblende schist. Northeast for a distance of approximately 24 miles there are no rock exposures. In T 46 N, Rs. 41 and 42 W, Michigan, the territory between the Marenisco and Turtle ranges is occupied by a complex of mica and hornblende schist and coarse grained amphibolite with a large amount of intrusive granite, greenstone and fresh diabase.

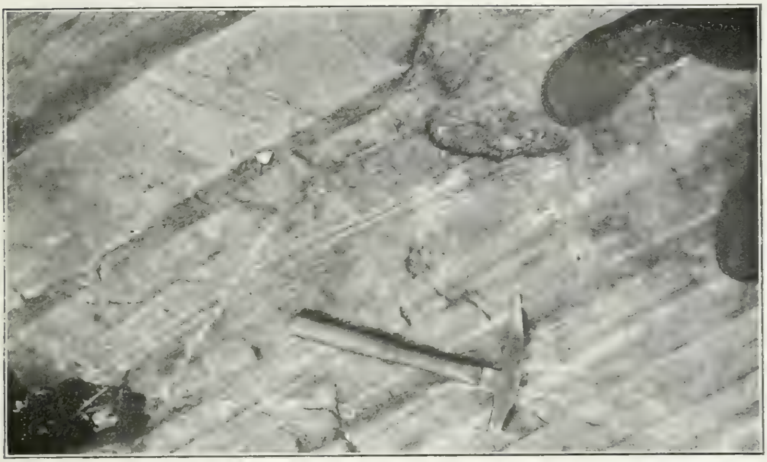
There is no certain evidence that any of these rocks are Archean and it is probable that the intrusives are Algonkian. The schists and gneisses are placed tentatively in the Archean because they appear on what seems to be an anticline separating the Marenisco and Turtle ranges and are plainly older than the other rocks which are igneous and intrusive in them. The Huronian rocks are also extremely metamorphic and therefore correlation on the basis of metamorphism or lithologic similarity with the Archean of other localities is not warranted.

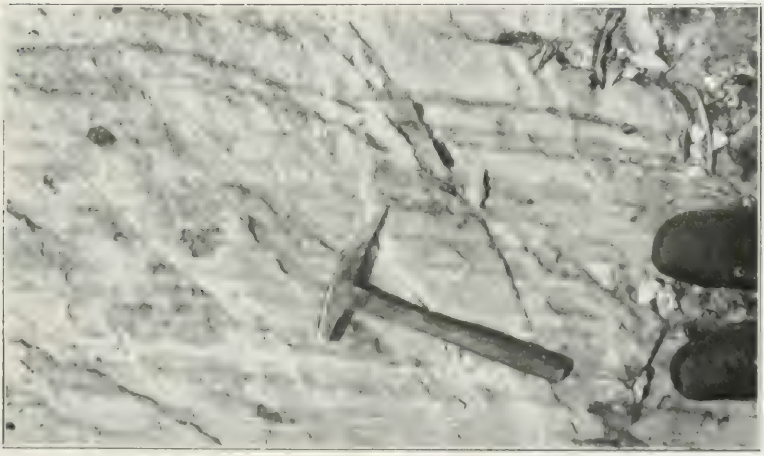
Mica Schist. The most interesting rocks in the southern area are the mica schists. In T 46 N, R 41 W, particularly in sections 13, 14, 15, 18, 29 and 30, outcrops of mica schist are associated with massive greenstone. Mica schist also occurs in association with greenstone in one exposure in section 30, T 46 N, R 42 W. Near the south quarter post of section 8, T 46 N, R 41 W, there is a small exposure of biotite schist intruded by granite. This is the only exposure known where granite is in contact with mica schist.

The mica schists are generally of light gray color; some are coarse and others are fine grained. A common feature of all of the exposures is the occurrence of an abundance of milky white quartz in blebs and stringers parallel to the schistosity. Here and there these stringers are minutely folded. Other quartz veins cut across the schistosity indifferently, apparently filling joint planes. At two localities in the south part of section 29 the mica schist shows a banding in addition to the ever present schistose structure. In many cases the plane of schistosity is inclined to the banding, but in general the two structures are parallel. At one locality the banding has a strike of N 25° E, the schistosity N 62° E. The dip of banding and schistosity is about vertical.

The mica schists are composed principally of quartz, biotite and limpid feldspar, with subordinate muscovite magnetite, sericite, garnet, epidote and apatite. The quartz, biotite and feldspar, which make up the mass of the rock, constitute an interlocking crystalline mosaic Locally the mica is muscovite but in general, biotite prevails. The biotite is definitely oriented, but the interlocking grains of quartz and feldspar do not, in the coarser grained rocks, partake of the schistose structure. In the finer grained varieties there is a tendency for elongation of many of the quartz and feldspar grains parallel to the biotite flakes. Quartz, the most abundant mineral, exhibits strain effects and inclusions in the coarse grained schists, but the absence of these features is characteristic of the finer grained facies. The feldspar, except in case of the biotite schists associated with the granite in section 8, T 46 N, R 41 W, occurs in small, limpid, unstriated grains and is very difficult to distinguish from the quartz. However, certain of the weak doubly refracting grains show brightly polarizing alteration specks, presumably sericite, and grains of this type have a uniformly lower index of refraction than the other grains which are clear and free from all alteration products. In addition, biaxial interference figures may be observed in some of the larger grains. The schist where intruded by granite shows considerable striated plagioclase feldspar, and is also fresher in appearance and rather coarse grained. Biotite alone exhibits parallel orientation; the quartz and plagioclase (about albite-oligoclase) form an allotrimorphic crystalline mosaic. Accessory minerals in the granitized schist are zircon, pyrite partly altered to red ferric oxide, a few grains of magnetite, epidote and apatite. The zircon, pyrite and magnetite are included in the biotite.

Origin of the mica schist. While we incline strongly to the view that the feldspathic mica schist is an altered sediment, the evidence is inconclusive. Rounded grains of quartz and feldspar are not uncommon, but in all cases they fit perfectly into the crystalline mosaic and can not be regarded as detrital with any degree of certainty. One or two doubtful indications of secondary enlargment were noted, but little reliance is placed on them. In the field, the schist is associated in almost every exposure with either diabase or massive greenstone. This association lead early to consideration of the idea that the schist might be a sheared phase of the massive rocks. Microscopic study of the greenstone and diabase shows, however, that these rocks are much more basic in composition than the schists. They are composed, dominantly, of green hornblende and basic plagioclase. Some specimens of the fresher diabase show traces of original pyroxene and the characteristic ophitic or lath shaped development of feldspar is in every instance preserved. The metamorphism of a rock of this type under conditions which would induce schistose structure would produce an amphibolite or hornblende schist rather than a typical quartz-mica schist. Furthermore it is possible to say with certainty that the massive greenstone intrudes the schist. The schist in fact seldom occurs except in association with massive greenstone. As a whole the schist is soft and easily eroded and therefore is more apt to be exposed in those places where it is partially protected by intrusive masses of greenstone of much greater erosive resistance. Consequently, it is probable that observation is confined to the most severely metamorphosed parts of





BANDED MICA SCHIST. SECTION 30, T. 46 N., R. 12 W.

the schist wherein evidences of sedimentary textures and structures have been obliterated. It is well known that contact metamorphism, even without addition or subtraction of material from extraneous sources, can change a pelite or psammite formation into a crystalline mica schist. Mention was made earlier in the discussion of the presence in certain outcrops of a banding at variance with the prevailing regional schistosity.

Intrusives. In addition to the mica schist the rocks of the southern area comprise amphibolite, hornblende schist, and intrusive greenstone, granite and diabase. These are certainly younger than the mica schist, and are probably to be correlated with similar intrusives in the Huronian sediments in T 46 N, R 42 W. The amphibolite and hornblende schist are in part derivatives of massive intrusive greenstone. Certain isolated outcrops may, however, be older and have no connection with the massive greenstone. The intrusives will be described later. For the present it should be borne in mind that intrusives are extremely abundant in the southern complex.

RELATIONS TO ADJACENT ROCKS.

Relations to Keweenawan. In section 13, T 46 N, R 41 W, Michigan, the steeply dipping and highly metamorphosed micaceous schists are overlain by the almost flat lying unaltered basal sandstone and conglomerate of the South Trap range. The conglomerate contains pebbles derived from the underlying schists.

Relations to Huronian. The relation of the southern schists to the Huronian rocks of the Marenisco range may only be inferred. The schist series lying south of the range is referred to the Archean for the following reason. These rocks lie at the eastern extremity of the territory between the Marenisco and Turtle ranges. The magnetic belts of these ranges mark the location of folded sedimentaries and lavas, a conclusion amply sustained by their linear character and the nature of the underlying rocks wherever exposed or opened in exploration. The gross structure between the Marenisco and Turtle ranges is believed to be anticlinal with the Huronian series exposed on either flank of the major fold.

The exposures along the Turtle range in T 46 N, R 41 W, Michigan, are effusive lavas with subordinate intrusive greenstone and diabase. At no place are these rocks in contact with the mica schist.

MIDDLE HURONIAN SERIES (ANIMIKIE).

The full succession of the Middle Huronian is exposed only in T 46 N, R 42 W, Michigan. The succession here includes basal graywacke-quartzite, iron formation and a vast thickness of slate occupying a belt not less than two miles wide between the iron formation on the south and the Presque Isle granite of the Gogebic range on the north. The entire succession with the exception of the central part of the slate is highly metamorphosed.

GRAYWACKE-QUARTZITE.

The base of the Middle Huronian series is highly metamorphosed quartzite and graywacke. The quartzite is exposed in a large outcrop in the NW$\frac{1}{4}$ of SE$\frac{1}{4}$ of section 7, T 46 N, R 41 W, and also occurs on the dump of a pit in section 12, T 46 N, R 42 W, where it is apparently in association with the iron formation. The quartzite is a hard gray, vitreous, fine grained aggregate of interlocking, crystalline, quartz grains, containing rounded grains of orthoclase and plagioclase, abundant chlorite, and a small amount of sericite as an alteration product of feldspar. In thin section, in ordinary light the outlines of original clastic quartz grains are made conspicuous by fringing shreds of chlorite, but under crossed nicols a crystalline mosaic appears in which the only indication of sedimentary origin are the rounded grains of feldspar.

In sections 22 and 23, T 46 N, R 42 W, are a number of outcrops of fine grained, banded graywacke associated with intrusive diorite and diabase. The bands vary from mere laminae up to an inch or more in width. In places differential weathering of the bands has given the rock a ribbed appearance. Near the contact with the intrusives the graywacke is usually greatly contorted. Under the microscope the graywacke reveals a crystalline aggregate of quartz, epidote and zoisite, with some secondary feldspar and a few shreds of green hornblende. The rock is thoroughly recrystalline and in some cases a schistose structure is produced by parallel alignment of the hornblende crystals. The banding is caused by alteration of zones of finer and coarser grained material. The least altered of these rocks are made up of finely crystalline quartz, secondary feldspar, badly altered to sericite, scattered needles of green hornblende, and a few specks of magnetite, epidote and chlorite. In general, the texture is that of a recrystalline rock, but there are many rounded grains of quartz which seem to be caught in a feldspathic cement.

The occurrence of the graywacke immediately south of the iron formation in sections 22 and 23, as well as its position on the strike of the quartzite exposed in section 12, T 46 N, R 42 W, and section 7, T 42 N, R 41 W, its mineral composition, and its structure are the basis of our belief that this formation is part of the basal detritus of the Middle Huronian series. The exposures are in all cases intruded by greenstone and diabase, or located a short distance from outcrops of igneous rocks. To the presence of these igneous intrusives must be ascribed the recrystalline character and the obliteration of the clastic texture of the graywacke when viewed under the microscope.

Neither the quartzite nor the altered graywacke were observed in contact with the Archean or any formation of the Huronian, but that both are stratigraphically below the iron formation is apparent from the field relations.

IRON FORMATION.

The iron formation of the Marenisco range is exposed in a number of pits and outcrops in sections 12 and 13, and in a few pits in section 22, T 46 N, R 42 W. The formation is also exposed in section 21, T 46 N, R 43 W, along the C. & N. W. R. R. track one half mile south of the station of Marenisco. From Marenisco southwest along the strike of the range there are no exposures, but diamond drill cores of iron formation were found at the Magnetic Center exploration in section 28, T 44 N, R 3 E, Wisconsin.

Lithology. The drill cores from the Magnetic Center exploration are a banded quartz-amphibole-magnetite rock. The banding is conspicuous on the polished sides of the core but on fractured surfaces close examination is necessary to distinguish the structure except where a wide band of light colored chert or quartz is present.

Proceeding from this locality northeast, exposures are first encountered on the C. & N. W. R. R. in section 21, T 46 N, R 43 W, Michigan, one half mile south of Marenisco station. The most striking characteristic of these outcrops is a conspicuous fine banding of various shades of gray, green and brown alternating across the face of the exposure in the plane of a well developed schistosity which is vertical and strikes in the general direction of the magnetic belt, N 55° E. Here and there are bands of dull gray to white chert, less persistent than the others, and broken into lenticular shaped masses resembling flattened fragments in an exceedingly schistose conglomerate. Blebs and stringers of quartz are abundant. Some of the bands are highly ferruginous, weathering to a rusty brown color.

The microscope reveals the presence of rounded clastic grains of quartz and feldspar embedded in a groundmass of finely crystalline chert, dirty greenish brown biotite, magnetite, carbonate (probably siderite) with subordinate amphibole and chlorite. The fine bands, so conspicuous on exposures, are caused by the alteration of bands of amphibole and biotite with bands of chert, magnetite and carbonate. Fragmental grains of quartz and feldspar are for the most part oriented with the long dimension of the particles parallel to the banding, but some of them show no tendency toward orientation. This rock is evidently a highly metamorphosed lean iron formation intermixed with clastic material.

The best localities for observation of the iron formation are the pits in section 22 and the pits and outcrops in sections 12 and 13, T 46 N, R 42 W, Michigan. A careful examination of the rocks at these localities has been combined with the study of a large number of thin sections. In general, the rock is a lean iron formation, intensely metamorphosed and, for the most part, typically banded, the bands varying in width from mere laminae up to one to two inches. The wider bands are mainly light colored, crystalline quartz. The darker and narrower bands contain quartz and iron bearing silicates and oxides. These bands are not uniformly continuous, the smaller ones often pinching out and dovetailing with the larger ones in an intricate manner. Thin veins of pyrite and carbonate cement innumerable fractures across the banding. Pyrite and perhaps pyrrhotite have been concentrated along some of the darker bands. Certain of the dump specimens are not banded, and as a rule iron amphiboles are abundant in this type. The rocks may be classified as follows: (1) Chloritic-sideritic-magnetitic schist, (2) manetitic-sideritic-quartz rock, (3) actinolitic-magnetitic schist, (4) grüneritic-magnetitic schist, and (5) chloritic-biotitic-magnetitic schist.

The prevalent type in the pits of this township is the *magnetitic-sideritic-quartz rock*. In hand specimens the most pronounced feature is the alternate gray and white banding mentioned before. It is made up of quartz and magnetite with subordinate siderite and considerable chlorite in occasional bands and small flakes. Hematite and pyrite are present but not abundant. The banded structure, which is such a marked macroscopic feature, is due to alternate zones of fine and coarse grained quartz. The banding is heightened by the concentration of magnetite in the zones of finer grained quartz. This mineral occurs in two forms; (1) as small grains with a tendency towards crystal development, and (2) in large irregular patches that commonly show considerable fracturing with development of hematite and siderite in the fracture planes. The siderite and hematite in these situations appear to be alteration products of the magnetite. In general, the siderite occurs in small patches and occasionally in bands or zones not directly associated with the large irregular patches of magnetite although the carbonate, with the exception of an occasional small crystal, is confined to the bands in which magnetite is concentrated. It is probable that the siderite is original except in the cases noted above, where it appears to be formed along the cleavage cracks of magnetite. In by far the larger number of cases the tendency is for the development of magnetite along the cleavage cracks and around the edges of the carbonate. Where the chlorite occurs in sufficient quantity to be a marked feature of the rocks as a whole it may be defined as a *chloritic-magnetitic-sideritic schist.*

The *actinolite-magnetite-schists* are usually dark gray and may or may not show banding. The bands vary from one inch to one eighth of an inch or less in width. The wider bands are predominantly finely crystalline quartz, magnetite and fibrous amphibole being concentrated in the narrower bands. Where the rock is not banded it is dark gray and shows the metallic luster of innumerable minute crystal faces of magnetite. In this rock the greenish yellow actinolite crystals seem to be collected in masses and rosettes. The banded types are made up of zones of finely crystalline quartz, alternating with zones of actinolite, magnetite and siderite. The quartz grains exhibit no trace of detrital origin such as rounded outlines or zones of secondary growth. While quartz is the most abundant mineral in the so-called quartz bands they contain a considerable amount of scattered siderite associated with the minute crystals of magnetite and occasional needles of actinolite. Alternating with the quartz are bands of magnetite, actinolite and siderite. The latter mineral occurs in every stage of alteration to actinolite, from pure crystals surrounded by needles of amphibole, through early stages of alteration in which actinolite occurs in the centers of the siderite grains along cleavage cracks, until, finally, the crystals of siderite can barely be discerned through the mass of actinolite fibres. In general, the center of these bands is occupied by unaltered iron carbonate, although in some of the narrower bands the alteration to actinolite has been complete. The amphibole is in its customary fibrous development. There is no alignment of the fibres. In the center of the bands and on the edges near the contact with the quartz zones the fibres lie at right angles to the banding and penetrate into the adjacent quartz grains. The magnetite is in well developed octahedra and is most abundant in the siderite-amphibole bands although it is present in much smaller quantities and smaller crystals in the quartz bands where it is closely associated with scattered grains of carbonate.

Thin sections of the *non-banded actinolite rocks* present a much different appearance. Siderite is not observed in rocks of this type. Upon a dull gray mosaic of small interlocking quartz grains there appear, as if painted, rosettes of actinolite through which are scattered idiomorphic crystals of magnetite. In the spaces between the rosettes of actinolite the finely crystalline mass of interlocking quartz grains appears. The actinolite occurs in rosettes of long, faintly green, almost colorless needles and in minute bundles between the quartz grains, the needles penetrating the adjacent quartz mosaic. Small individual needles are also included in single individuals of quartz. Crystals of magnetite are scattered haphazardly through the rosettes of actinolite although there is sometimes a tendency towards concentration at the center and at the junction of two rosettes. In areas where the quartz predominates, the magnetite, while not entirely absent, is represented only by occasional and usually small crystals.

Grunerite-magnetite-schist occurs in a small outcrop near the pits in section 12. The variety cummingtonite has not been identified but as this mineral is rather common in the metamorphic iron formations of the Lake Superior country it is probable that a more careful search would result in its identification.

So far as it is possible to determine from the very limited data available, the iron bearing rocks of the Marenisco range do not differ from the metamorphic phases of the iron formation on the other Lake Superior ranges and there is no reason to believe that the Marenisco iron formation differs from them in origin. The abundance of carbonate and its apparent close genetic relationship with the magnetite and iron amphibole together with the bands of finely crystalline chert point to the primary deposition of cherty iron carbonate. There is evidence that locally, at least, the deposition of non-clastic ferruginous material was accompanied by clastic sedimentation.

Ore bearing possibilities of the iron formation. With regard to the ore bearing possibilities of the iron formation of the Marenisco range attention should be once more directed to a statement made earlier in this discussion, viz., that the range is everywhere characterized by strong to violent magnetism. The iron bearing rocks throughout the entire range are highly metamorphosed. The possibilities for discovery of valuable ore bodies are not promising. It is of course possible that some portions of the iron formation may have escaped the general intense metamorphism, and that in such places, ore bodies may have been concentrated.

Igneous intrusives in the iron formation. The iron formation exposed in the pits and outcrops in T 46 N, R 42 W, is closely associated with massive igneous intrusives. Considerable igneous material occurs on the dumps of some of the pits in iron formation. Many outcrops of altered diorite and diabase are in close proximity to the pits and a short distance southeast of the pit in section 22 is an area of granite, probably intrusive. Intrusives were nowhere observed in contact with the iron formation, but there can be no doubt that the latter has been severely altered by igneous intrusion. The presence of iron silicates, the completely crystalline character of the quartz, abundant magnetite, almost total lack of hematite, and igneous injection, described below, all point to contact action as the cause of the extreme metamorphism of the iron bearing rocks.

Specimens from the dump of a pit near the center of section 22 are of special significance inasmuch as they show intimate injection of igneous material. These rocks are typically quartz-magnetite schists, dark gray to black and strongly magnetic. The noticeable feature is the presence of thin veins and streaks of red feldspar which cut across the banding of the rock in some places and in others are parallel to it. A slide made from one of these specimens cut one of the red veins and served to confirm the field determination of its mineral composition. The rock is made up of bands of finely crystalline quartz and magnetite alternating with bands composed of small interlocking grains of altered feldspar with subordinate quartz and considerable chlorite. The feldspar is filled with fine red dust and shows considerable alteration to sericite. The contrast between the clear, fresh quartz and the cloudy feldspar is marked. The feldspar in the bands is in a crystalline aggregate and the individual grains are small and unstriated. The uniformly lower index of refraction of the feldspar compared with the quartz, the observation of biaxial interference figures, and the character of the alteration product, leaves no doubt that these small grains were correctly determined. There is a tendency for chlorite to concentrate between the quartz-magnetite and the feldspathic bands, although it is scattered in flakes throughout the slide. Magnetite is present throughout the rock in well developed octahedra but is concentrated for the most part in the feldspar free bands.

No intrusive igneous material was found in or near the exposure of iron formation at Marenisco or at the Magnetic Center locality at the western extremity of the range, but the character of the rocks in these localities points toward metamorphism through igneous intrusion. In section 4, T 45 N, R 44 W, Michigan, there is a knob of granite projecting above the drift. This outcrop is a short distance north of the line of maximum attraction in the south magnetic belt and there can be little doubt that it is intrusive into the adjacent magnetic rocks.

THE SLATE FORMATION.

The slate formation in T 46 N, R 42 W occupies a belt about two miles wide north of the iron formation. Outcrops are not plentiful but their distribution together with the character of the topography and the absence of exposures of other rocks warrant the assumption that the slate underlies practically the entire area. The formation strikes northeast and the secondary cleavage is, on the whole, inclined steeply southward. The slate is probably as thick as the Tyler formation of the Gogebic range with which it is apparently lithologically identical, but as in the case of the Tyler, its apparent thickness of about 9,000 feet may be in considerable measure accounted for by close folding.

Lithology. The main types are gray, grayish green and black slate and fine grained graywacke. Exceptional phases of local importance are chlorite, mica, and hornblende schists. The hornblende schists are confined to the borders of the slate belt near the contacts with the southern intrusives and the northern Presque Isle granite. In the central portion of the belt the rocks show no evidence of extreme metamorphism. Microscopic examination shows that the slate and graywacke are composed mainly of fine fragments of orthoclase, plagioclase and quartz. The central part of the formation is cut by veins of quartz which become increasingly important near the borders of the belt. In the neighborhood of the intrusives these veins are often noticeably feldspathic.

The most favorable localities for study of the unaltered slate of the central part of the belt are the exposures near the quarter post between sections 8 and 17 at the locality known as Nelson canyon, the extensive outcrops at Judson Falls on the slate river and the exposure at the outlet of the Slate river into Lake Gogebic. At Nelson canyon, a tributary of the Slate river has cut a gorge 375 feet long, 20 feet wide, and from 5 to 25 feet deep, parallel to the strike of the slate. At Judson Falls the river tumbles in a series of low cascades over the upturned edges of the slate for a distance of 500 feet. The rock at both localities is gray slate, very uniform in appearance, with here and there coarser graywacke phases. At Nelson canyon the slate contains reddish stained breccias which apparently caught the eye of the early explorer for iron ore and led to the sinking of a few shallow pits in the vicinity. At the mouth of the Slate river the rock is predominantly a fine grained graywacke with subordinate slaty phases. A peculiar feature of the coarser varieties are ellipsoidal cavities from one to three inches long, one half inch wide and from one half to one inch in depth. The cavities are in all cases oriented in the direction of schistosity.

The southern exposures of the slate series are more or less metamorphosed although their clastic character is commonly recognizable in the field. In the north half of section 20 there are two small outcrops of fine grained granitic material injected parallel to the schistosity. The schistosity is pronounced but the cleavage is less perfect than that of the northern exposures. As determined in thin sections this rock is composed of quartz, biotite, orthoclase, plagioclase and chlorite with scattered small crystals of apatite and tourmaline. The original clastic structure is plainly apparent in the rounded character of the larger grains of feldspar. The biotite is plentiful in small grayish brown flakes with parallel alignment. The space between the larger fragments is filled with an interlocking mosaic of quartz, secondary limpid feldspar and biotite.

About 650 paces north of the south quarter post of section 15 is an outcrop of dense massive graywacke, the clastic structure of which is still plainly evident under the microscope, although a partial recrystallization has taken place. In the same section there is a small outcrop of the slate series in contact with diabase. Near the contact all traces of sedimentary textures in the slate has been obliterated by recrystallization.

Relations of the slate to adjacent formations. So far as known the contact between the slate and the underlying iron formation is not exposed but the relations are believed to be those of conformity.

The slate formation is intruded by the Presque Isle granite. The actual contact is exposed in two localities in section 4. Sheared chloritic schist occurs adjacent to the contact, but a short distance away the slate differs but little in appearance from the typical exposures in the center of the belt. The schist adjacent to the contact is cut by abundant stringers and veins of granitic material. In one place blocks of the schist are imbedded in the granite.

Dark colored fine grained quartz-biotite schists occur along the *east border* of the great granite ridge that forms the west shore of Lake Gogebic in section 33, T 47 N, R 42 W. The biotite schists, some of which are hornblendic, are intimately injected by granite and pegmatite and present the appearance of banded and contorted gneiss. Whether these biotite schists are a part of the slate series along the *south border* of the Presque Isle granite is entirely conjectural but their occurrence east of the granite is of some interest and furnishes the only clue to the nature of the rocks occupying the low ground in the southeast part of T 47 N, R 42 W.

IGNEOUS ROCKS.

The entire Huronian succession is intruded by both acid and basic rocks and the iron formation and basal quartzite are associated with extrusive flows and possibly tuffs.

Extrusives.

Altered Porphyrites. In section 7, T 46 N, R 41 W, about 200 paces north of an outcrop of the basal quartzite and in the strike of the iron formation in T 46 N, R 42 W, there is an exposure of schistose porphyritic lava. The outcrops occur for a distance of 30 paces in a narrow gorge on the west branch of Trout Creek. The lavas present some peculiar and interesting features and will, therefore, be described in some detail. They are highly metamorphosed and schistose parallel to the prevailing strike. The dip of the schistosity is nearly vertical or inclined at a steep angle southward. The least altered rocks are plainly porphyritic but those that have suffered the greatest deformation are beautifully crenulated schists in which the phenocrysts may be detected only by careful search. The crenulated structure is caused by minute folding of the fibrous amphibole of the ground mass which has produced perfect false cleavage*. In the schistose specimens phenocrysts of red feldspar, showing in may cases good crystal form and attaining the size of one fourth inch in the longer dimension, are embedded in an aphanitic dull gray ground mass. At one place for a space of a few feet the rock has been brecciated and recemented by calcite which gives it the appearance of dolomite or limestone containing scattered nodules of chert. Under the microscope, however, these fine grained gray cherty appearing fragments are seen to be porphyrite differing in no respect from other porphyries in this locality. The porphyrites are cut out by a narrow dike of fresh diabase.

Microscopic examination of the porphyrites discloses badly altered and mashed phenocrysts of feldspar and quartz, feldspar predominating, embedded in a ground mass, which, in the schistose type, is composed of a fine grained fibrous mass of green hornblende or actinolite with abundant minute grains of epidote. Lesser quantities of magnetite, biotite, chlorite, quartz, limpid feldspar and calcite are present. Where the small fibers of amphibole are thrown into a series of close minute folds the slide shows beautifully the crenulated or helicoidal structure, while the rock as a whole has a well developed false cleavage. Where the rock is more massive in character the ground mass is made up of a very fine grained interlocking mosaic of unstriated feldspar, subordinate quartz, grains of epidote, a few scattered flakes of biotite, green hornblende and occasional grains or laths of magnetite. The phenocrysts are orthoclase with considerable subordinate plagioclase. In one specimen coarse grained granulated areas of quartz were noted, probably representing original quartz phenocrysts. Except in the freshest types the phenocrysts show crushing and granulation around the edges and where the ground mass is crenulated the large crystals are often bent and fractured and the cracks filled with a mosaic of quartz grains. In all cases the feldspar crystals are badly altered and some of the orthoclase is filled with fine red dust. Traces of carlsbad twining are common but the laminations characteristic of albite are rare. Alteration of the orthoclase produces sericite, of the plagioclase, epidote, biotite zoisite and albite. A peculiar and persistent feature of

*Leith, C. K. Bulletin 239, U. S. G. S., page 49, Pl. XIV B.

the porphyrites is the occurrence of micropegmatitic phenocrysts of quartz and orthoclase, quartz always subordinate. The structure is emphasized by the simultaneous extinction of the angular quartz areas and the contrast between the clear quartz and the badly altered orthoclase. Phenocrysts of this type have been noted by Iddings in rhyolite from the Eureka district of Nevada* and in obsidian from Yellowstone Park**. The ground mass of the non-schistose variety presents some suggestive features in the arrangement of epidote grains when observed in ordinary light. Fairly clear traces of flow structures appear and also less distinct indications of original perlitic parting.

There can be no doubt that the rocks in this vicinity are metamorphosed effusive lavas of composition near trachite. The determination of original character is rendered difficult by extreme alteration.

In section 29, T 46 N, R 43 W, on the south edge of the magnetic belt there is an exposure of similar altered effusive porphyrites intruded by granite.

Hornblende Schist. Closely associated with the iron formation in section 15, 21 and 22, T 46 N, R 42 W, Michigan, are a number of exposures of hornblende schist. They are dark gray to greenish black and are extremely fine grained and schistose. The schistosity controls a platy parting, in many cases so perfect as to give the rock the appearance of slate. Rarely a faint banding may be observed. Under the microscope the schists are seen to be composed almost entirely of a matte of small prisms and needles of compact green hornblende. Filling the interstices between the amphibole fibers are minute clear grains of limpid feldspar (albite) with subordinate quartz. Magnetite in small lathshaped individuals, oriented parallel to the schistosity, is abundant.

No traces of original structure or texture remain and it is therefore impossible to assign a definite origin to these schists. It is regarded as possible that they are metamorphic tuffs or squeezed basic lavas, an inference based upon the fact that in mineral composition and structure they are almost identical with the ground mass of the altered porphyrites found in section 7, T 46 N, R 41 W and at other localities on the Marenisco and Turtle ranges.

In section 15 the hornblende schists are intruded by massive greenstone, and in sections 21 and 29 by granite.

Relation of the Effusives to the Huronian Rocks. The outcrops of fine grained hornblende schist thought to be metamorphic lavas or tuffs, are closely associated with the magnetic belt marking the position of the iron formation in T 46 N, R 42 W, Michigan. Outcrops

*Monograph 20 U. S. G. S., p. 375. Plate V-2

**Seventh Annual Report, U. S. G. S., pp. 274-276. Plates XV and X-2 of this rock were found both north and south of the pits in iron formation in section 13. If these schists are altered lava flows it is probable that they are interbedded with the lower portion of the Huronian series.

The porphyrites exposed along the west branch of Trout creek in section 7 are located about 250 paces north of a large exposure of basal quartzite. The relation between the lavas and quartzite is unknown. About all that can be said is that the lavas dip under the quartzite but whether they are stratigraphically above or below it can not be determined. The attitude of the regional schistosity and the general succession of the Huronian series indicate that they are above the quartzite.

Intrusives.

The following discussion is applicable only in T 46 N, Rs. 41 and 42 W, Michigan. Southwestward, intrusive rocks are found in contact with the greenstone porphyries in section 29, T 46 N, R 43 W, Michigan. It was noted in connection with the description of the iron formation that a large exposure of granite occurs in the middle of the magnetic belt in section 4, T 45 N, R 44 W, Michigan. The position of this outcrop with reference to the magnetic belts in that locality suggests that the granite is intruded into the Huronian series. No other Huronian intrusives are known southwest of T 46 N, R 42 W, Michigan. However, the strong magnetism together with the metamorphic character of the exposed rocks is presumptive evidence that igneous intrusion has played an important role in metamorphism throughout the entire range.

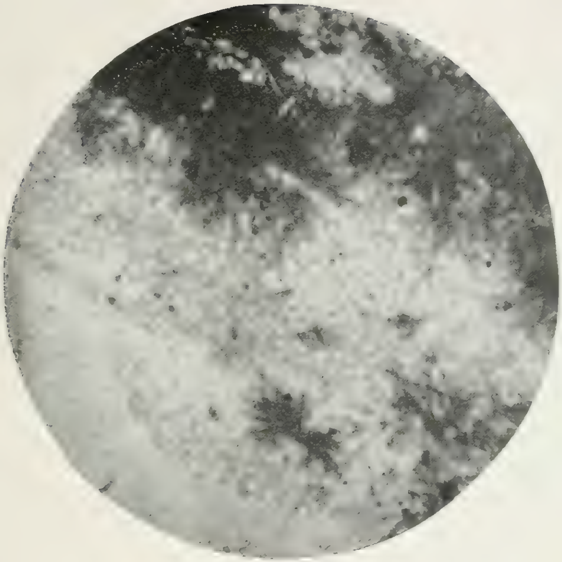
Inasmuch as the intrusives form the most abundant exposures in T 46 N, Rs. 41 and 42 W, Michigan, and are believed to have been the most important agents in the metamorphism of the Huronian rocks they will be dicussed in considerable detail.

The following description is not a thorough treatise of these rocks. From data at hand regarding the field relations and the limited number of thin sections available for study we can attain no more than a broad view of the field as a whole with the hope of bringing out the more general relations and characteristics of the intrusives.

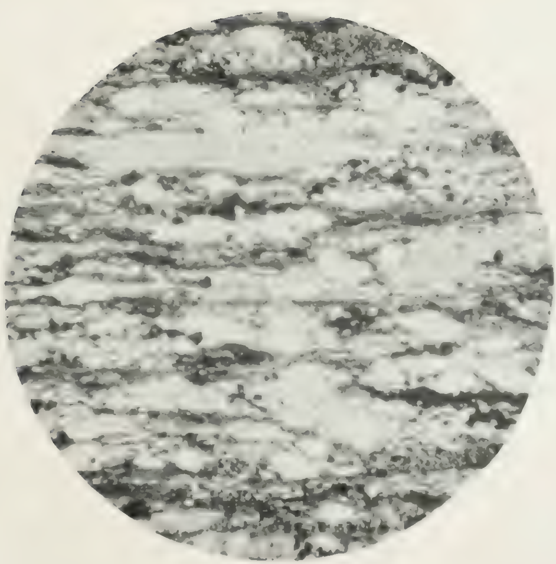
From the standpoint of composition, the intrusives fall, roughly, into three general classes; viz., *hornblende bearing greenstone, granite, and fresh massive diabase.* All three types are found in contact with both the Huronian rocks and the southern schist series. Whether the intrusives in the southern schist belong to an earlier period of igneous activity, or are contemporaneous and to be correlated, in whole or in part, with similar rocks intrusive in the Huronian series can not be determined with certainty. However, consideration of their petro-

(A). (Without analizer, X 16). Amphibole-magnetite-quartz rock from test pits in the NW¼ of NW¼ of section 12, T. 46 N., R. 41 W., Michigan. The rock is typical of the metamorphic iron formation found on this part of the Marenisco range. The black specks are magnetite, and fibrous mineral is grünerite and actinolite, the light areas are finely crystalline quartz and iron carbonate. The intimate association of the amphibole and magnetite with the siderite, while not apparent in the plate, is a marked feature of this rock.

(B). (Without analizer, X 16). Iron formation with intermixed detrital material from exposure along the Chicago and Northwestern Railway one-half mile south of the station of Marenisco, Michigan. The clastic grains of quartz and feldspar are easily seen. The remainder of the rock is composed of magnetite, chert, carbonate, amphibole and chlorite.



(A)



(B)

Plate VI.

(A). (Without analizer, X 16). Greenstone porphyrite from SW¼ of NW¼, section 7, T. 46 N., R. 41 W., Michigan. This is one of the more basic varieties from this locality showing the development of false cleavage in the arrangement of the hornblende needles of the groundmass. Near the center of the plate is a phenocryst of plagioclase showing saussuritic alteration in the center. Under crossed nicols the plagioclase phenocryst exhibits granulation around the edges.

(B). (With analizer, X 16). Feldspathic biotite-schist from Archean (?) area lying south of the east end of the Marenisco range. This is one of the coarser grained and thoroughly crystalline types. It is composed of plagioclase (albite and albite-oligoclase) quartz and biotite. Accessory minerals are sericite, epidote, apatite and zircon. These rocks are believed to be altered sediments.

(A)

(B)

graphic character and, more especially, the relation of the various types to each other in both areas renders it likely that in the case of the diabase and granite, and probably in large part the greenstone also, most of the similar intrusives in both the Huronian and Archean are of about the same age.

That the three main types, greenstone, granite, and diabase, represent three fairly definite periods of igneous activity seems to be established from a consideration of the field evidence. A more detailed study would undoubted modify this statement to a considerable extent, and would probably furnish evidence of a greater number of periods of intrusion, but it is believed that these would be largely in the nature of substages under one or more of the three major divisions.

The earliest intrusives are the greenstones. These rocks comprise altered diabase, diorite, and possibly gabbro. They are regarded as older than the fresh diabase and granite because where the relations were observed, the granite and diabase intrude the greenstone. Furthermore, the greenstones are in all cases badly altered and largely converted into schists in which nearly all, and in extreme cases all, traces of original textures and structures are obliterated. On the other hand, the granite, while in places rendered gneissose, is generally massive and fresh in appearance. The characteristic lath-shaped feldspar is a pronounced feature of the diabase. Thin sections exhibit fresh feldspar and the augite shows little uralitization.

While the evidence that the diabase and granite are younger than the greenstone is conclusive, the relation between the diabase and granite is obscure, as no contact of the two were observed. The extreme freshness of the diabase coupled with the fact that the granite nowhere intrudes the Keweenawan, whereas the diabase does, lends presumption in favor of the older age of the granite.

The most abundant types of intrusive rocks are *hornblende bearing greenstone and green schists.* The only mineral that can be universally recognized in hand specimen is green hornblende. Occasionally, in the more massive varieties, feldspar, or rather gray saussurite, can be recognized in blotches between the green hornblende crystals. In general, the structure is massive but where the rocks are in contact with granite they are characterized by a markedly schistose structure and development of considerable biotite which may entirely replace the hornblende. Near some contacts the schists are cut by many stringers of granitic material and pegmatitic veins and here and there blocks of schist are enclosed by granite. In other cases the contact is sharp and about parallel to the strike of the prevailing schistosity.

The most striking and constant features of the greenstone are the universal presence of green hornblende and the badly altered condition of the rock as a whole. The minerals are green hornblende, plagioclase, quartz, chlorite, biotite, epidote, magnetite, leucoxine, calcite, zoisite, saussurite, sericite, rutile, anataze and apatite. Badly altered original feldspar with a tendency toward idiomorphic development in the prism zone is ordinarily present in the massive types. Traces of ophitic and granitic textures are not uncommon but more often, even in the massive types, original textures and structures are nearly obliterated. The feldspar is almost destroyed, but obscure twinning lamellae are occasionally visible in a mass of alteration products. The common alteration products of the feldspar are quartz, albite, epidote and calcite. Cloudy saussurite is less often observed. The hornblende is in large green fibrous individuals generally showing a tendency towards crystal development in the prism zone but fraying out at the ends. In some cases this mineral is compact but in general it is sedgy and fibrous. Where the hornblende is compact it is commonly cellular. Alteration of the hornblende to chlorite may proceed to such extent that chlorite predominates over the amphibole. No trace of original augite occurs although hornblende is occasionally pseudomorphous after the pyroxene. Biotite is a minor constituent of the massive greenstone and occurs in part as a parallel intergrowth with hornblende, and in part as an alteration product of feldspar. Irregular grains of epidote are abundant. Magnetite is an important accessory mineral, largely associated with clusters of rutile or surrounded by leucoxine. Irregular blotches and small grains of calcite are very common.

In summary, the greenstones are all badly altered; green hornblende is a universal constituent; wherever traces of original texture or structure remain they are those of igneous rocks. Owing to the badly altered condition of the feldspar, and the entire absence of primary augite it is extremely difficult to define the exact original character of the rock from which they were derived but the majority are probably altered diorites and diabase. Hornblende pseudomorphs after augite probably means that gabbro is included in the parent rocks. However, the common idiomorphic development of feldspar in the prism zones, and the development of secondary albite and quartz rather than saussurite favor the assumption that diorite or diabase was the prevailing original rock. On the other hand, the tendency of the pyroxene to pass over into green hornblende or uralite may account for the present apparent absence of rocks of the gabbro type.

Granite. Granite is exposed in two areas in the southwest portion of T 46 N, R 42 W, and the west central portion of T 46 N, T 41 W. The rocks are light gray and pink and for the most part massive and fresh in appearance. Near the contact with the greenstone the granite is usually gneissose. In texture it varies from fine grained normal granite to coarse pegmatite. The minerals include orthoclase, plagioclase, microcline, quartz, biotite, sericite, chlorite, hematite, pyrite and apatite. The orthoclase and plagioclase show considerable alteration but the microcline is very fresh. The granite exhibits no other petrographic features of importance.

Diabase. Fresh massive diabase occurs in abundance in dikes and small knobs. It is dark greenish gray to black with an occasional outcrop showing a reddish tinge. The rock is easily recognized by the universal presence of lath shaped feldspar. Many of the dikes cut the greenstone at wide angles to the prevailing schistosity. Under the microscope the diabase appears to be very fresh or only slightly altered.

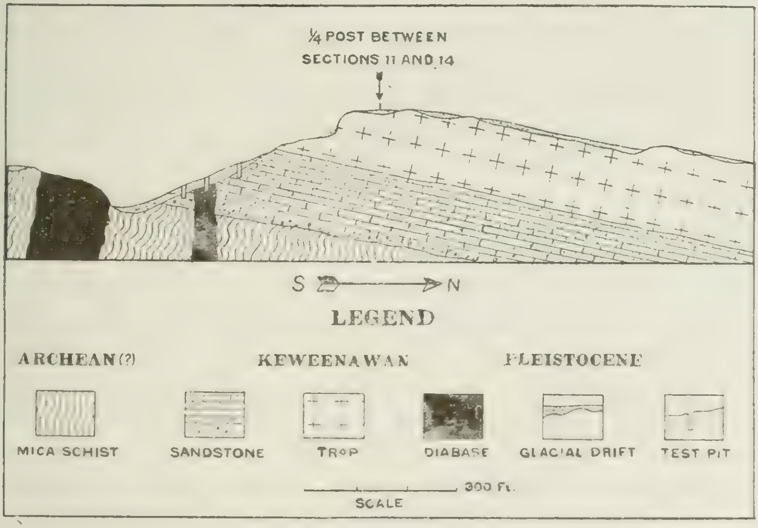


Figure 3. Diagram showing relations between Keweenawan sandstone, trap and intrusive diabase in sections 11 and 14, T 46 N, R 41 W. (After Seaman).

The minerals are plagioclase, augite, olivine, uralite, serpentine, magnetite and hematite. The texture varies from fine grained basaltic to coarse grained. The feldspar is idiomorphic giving the rock a well developed ophitic texture. The interstitial material is augite, somewhat altered to uralite and olivine showing alteration to serpentine, hematite, and magnetite.

Relations of the Intrusives to the Algonkian and Archean. Diabase is intrusive into the lower sandstone member of the Keweenawan in section 14, T 46 N, R 41 W. This relationship was noted by A. E. Seaman* in 1891 during the examination of the South Trap range.

*Unpublished field note. Michigan Geological Survey. Notebook 8[illegible]

There are a number of pits on the slope of the rise leading to a steep southwest facing bluff of Keweenawan trap (see *Fig. 3*, reproduced from drawing in Seaman's notebook). Diabase, showing the characteristic lath shaped feldspar, occurs in a shaft 35 feet deep about half way up the slope of the hill. About 35 feet southwesterly from the shaft and 15 feet down the slope is a shallow pit of sandstone (quartzite). Seaman describes this occurrence as follows. "The rock is quite hard and appears to be indurated by the diabase. The dip is under and toward the diabase at an angle of about 12°. The rock is composed of finely rounded grains of quartz and minute reddish specks of feldspar material evenly distributed through the mass with what appears to be a siliceous content." Twenty five feet southwest of the pit in sandstone and about 20 feet lower is another pit "in a somewhat closely consolidated aggregate of rounded grains of quartz and feldspar with a cement of iron oxide and silica. The dip here is the same as in No. 2 and the rock bears no evidence of disturbance. The strike as indicated by the dip is a little south of east." The above facts establish with certainty that the diabase is later than the lower sandstone member of the Keweenawan series. Correlation of the many diabase dikes and knobs south of this locality with the rock here exposed must rest on lithological similarity alone. Fresh diabase intrudes sedimentary members of the Huronian as well as the greenstone effusives of probable Huronian age in section 7, T 46 N, R 41 W. It also intrudes the mica schist on the southern Archean area, and the northern Laurentian granite.

The southern granite was not observed in contact with the Upper Huronian sediments, but certain of the specimens from the test pit dumps, section 22, T 46 N, R 42 W, show intimate injection of feldspathic material and the slate formation in section 20 of the same township is cut by narrow pegmatite dikes. In sections 29 and 30, T 46 N, R 42 W, granite is intrusive in fine grained hornblende schist described as metamorphic Huronian lava or tuff. The mica schists of the southern complex are intruded by granite in section 8, T 46 N, R 42 W. Aside from the above occurrence granite was found in contact only with greenstone.

The predominating intrusive in T 46 N, Rs. 41 and 42 W, as before noted, is the greenstone. Actual contacts between this rock and the micaceous schists of the southern complex are plentiful and in all cases the greenstone is intrusive in the schists. In section 22 the greenstone intrudes the graywacke at the base of the Upper Huronian. Although the greenstone is not known to intrude the iron formation, abundant outcrops of the former in close proximity to the test pits, the finding of igneous material mixed with the iron formation in some of the pits, and the general metamorphic character of the iron formation are evidence that the greenstone is also intrusive into the iron bearing rocks. The coarsening of grain and the tendency toward recrystallization shown by the southern part of the slate series is presumptive evidence that this formation has also been intruded by igneous material, although it is apparent from the character of the central exposures and general lack of outcrops of igneous rocks inside the slate area that this formation has been the least affected by the tremendous igneous activity which wrought such extreme metamorphism in the two lower formations.

There can be no doubt that the metamorphism of the Huronian rocks, both sediments and lavas, is mainly the result of igneous intrusion and injection. The type of metamorphism is that characteristically induced and affected by igneous action. Abundant iron amphibole and magnetite, the completely recrystalline character of the quartz, the occurrence of intimately injected feldspathic material in the iron formation and the entirely recrystalline character of the basal quartzite and graywacke are evidence of metamorphism induced by igneous intrusion.

CHAPTER V.

GEOLOGY OF THE TURTLE RANGE.

R. C. ALLEN AND L. P. BARRETT.

INTRODUCTION.

The Turtle Range extends from T 41 and 42 N. R 1 W, Wisconsin, northeast about 76 miles to the central portion of T 46 N. R 40 W, Michigan. where it is cut off by the overlapping Keweenawan rocks of the South Trap Range. The range has been traced by magnetic survey about six miles farther east underneath the Keweenawan sandstones and trap to the vicinity of Barclay in T 46 N. R 39 W. (?) Its position is marked. except for short breaks at each extremity. by a continuous magnetic field. In many places there are double. triple. and even quadruple parallel belts. The Turtle range is separated from the Marenisco range north of it by a territory from two to seven miles wide in which there is little magnetic distortion and. except in the northeastern portion. no rock exposures. The geology of the territory between the two ranges was described in connection with the Marenisco range under the heading, "Southern Archean Area."

The Turtle range is separated for the greater part of its extent from the Manitowish ranges south of it by a similar territory almost devoid of rock exposures and characterized by absence of magnetic belts. In places, however, the Turtle and Manitowish ranges are apparently connected by magnetic belts bridging the stretch of non-magnetic territory, although in no instance can a magnetic belt of either range be traced to a direct connection with a magnetic belt of the other. This relationship is shown on fig. 1. In T 45 N. R 41 W. Michigan. the magnetic belt which has an east west strike through the south half of the township to the east takes a sudden turn to the north and can be traced as far as section 2 of the former township. There is an apparent connection of the Turtle and Manitowish ranges in T 43 N. R 6 E. Wisconsin. in the vicinity of sections 14 and 15. In T 41 and 42 N. Rs. 2 and 3 E Wisconsin, there are nine parallel magnetic belts separated by narrow intervals of non-magnetic territory. Of these we include the three south belts in the Manitowish range and the six north belts in the Turtle range. Rock exposures are known in the area between the two ranges only at the northeastern extremity in T 46 N, R 39 W, and T 45 N, R 39 W, Michigan.

The Turtle range comprises rocks of both the Middle and the Lower Huronian series. There are exposures and explorations on its opposite ends, but its middle section of 25 miles from the Banner locality in section 1, T 45 N, R 43 W, Michigan, southwest to Mercer, Wisconsin, is entirely drift covered. The succession and character of the sedimentary rocks are determined mainly from data obtained from explorations for iron ore. Natural exposures of the sediments are almost entirely lacking but in some localities there are abundant exposures of the associated intrusive and extrusive igneous rocks.

Explorations for iron ore were conducted many years ago in Wisconsin at the old Michigan mine in section 22 and at the Broomhandle location in section 29, T 42 N, R 1 E; on the Lucas-Ford and Whiteside farms in sections 5 and 3 T 41 N, R 1 E, at other localities in this township, and in T 42 N, R 2 E. In Michigan the only exploration of importance is at the Banner mine in section 1, T 45 N, R 43 W. Recent diamond drilling by R. B. Whiteside and associates in section 4, T 41 N, R 1 E, Wisconsin; by the F. I. Carpenter syndicate in the vicinity of Mercer and Winegar, Wisconsin, and by the E. J. Longyear Company at the Banner locality, has added definiteness to some of our earlier conceptions of the geology of the Turtle range and has furnished the only evidence of the occurrence of the Lower Huronian series. As in the case of the Marenisco range, we know of no reference to the existence of the Turtle range in geological literature. In 1877, F. H. King* mentioned the occurrence of granite, hornblende, and mica schist on the Turtle river in the southern part of T 41 N, R 1 E, and the occurrence of greenstone at Turtle Falls in section 6, T 42 N, R 3 E, Wisconsin.

The following expresses the succession of formations so far as known:

*Geol. of Wisconsin, Vol. IV, Part IV, Geology of the Flambeau Valley, by F. H. King.

SUCCESSION ON THE TURTLE RANGE.

Keweenawan (?)		Intrusive diabase, granite and greenstone.
Algonkian / Huronian	Middle Huronian (Animikie)	Granite Effusive, agglomeratic and ellipsoidal greenstone. Basic tuffs (?). Black slate and graphitic schist. Iron formation. Quartzite and mica schist.
	Unconformity (?)	
	Lower Huronian	Mica schist (May be Middle Huronian.) Dolomite and dolomitic quartzite. Quartzite.
	Unconformity	
Archean	Keewatin (?)	Mica schist and green schist.

ARCHEAN.

With the exception of those described in connection with the Marenisco range, exposures of Archean rocks are confined to the territory south of the east extremity of the range.

The mica schists and banded mica and hornblende gneisses exposed along the Flambeau River in T 41 N, R 1 E; T 41 N, R 2 E; and T 42 N, R 2 E, Wisconsin, are assigned doubtfully to the Archean merely because there is no evidence of later age. These were described by King in 1877. Garnetiferous feldspathic biotite schist occurs also in test pits near the N¼ corner of section 11, T 41 N, R 1 E. The strike of the gneissose and schistose structures of these rocks is in general N 45° to 60° E. The schist from the pits in section 11 is very similar to the mica schist from the Southern Archean area of the Marenisco range.

HURONIAN GROUP.

LOWER HURONIAN SERIES.

Dolomite and quartzite. The Turtle range has been cross-sectioned by recent diamond drilling at Winegar, Wisconsin, by the F. I. Carpenter syndicate, and at the Banner location, Michigan, by the E. J. Longyear Company. At both localities dolomite underlies a slate iron formation series. The dolomite is massive, light colored and recrystalline, very similar in general to the Lower Huronian dolomite formations of the Marquette, Menominee, Crystal Falls, and Gogebic districts but apparently lacks the characteristic chert bands of these formations. The dolomite in the Winegar section is almost pure calcium magnesium carbonate and contains few other minerals or impurities. Cores from a drill hole on the south end of the Winegar section show a dolomitic quartzite with abundant development of tremolite; the hole on the extreme opposite end of this section shows a vitreous quartzite and mica schist intruded by granite and greenstones. It is therefore possible that the dolomite is underlain by quartzite in which event the analogy between the Lower Huronian here and on other Michigan ranges is practically complete.

There is evidence in the drill hole sections at Winegar that the dolomite is strongly developed; it can hardly be less than 1000, and it may be as much as 2000 feet thick.

The drilling does not determine an unconformity between the dolomite and the overlying slate-iron formation series for none of the holes cross the contact horizon. On the basis of analogy with other Michigan ranges unconformable relations may be assumed pending definite determination.

MIDDLE HURONIAN (ANIMIKIE) SERIES.

At the west end of the range the Middle Huronian is represented by quartzite, iron formation, and slate, the succession characteristic of this series in the greater part of the Lake Superior region. In the east central portion of the range, at the Banner mine and at Winegar, black slate apparently underlies the iron formation, and at both localities the rocks are compressed in close synclinal folds and the formation overlying the iron bearing rocks has been removed. The Middle Huronian series is associated with effusive greenstones showing in many places ellipsoidal and agglomeratic structures and porphyritic textures. Rocks of this type are abundantly exposed from Mercer, Wisconsin, southwestward to the vicinity of the old Michigan mine. On the opposite end of the range from the Banner location northeastward outcrops of effusive greenstones are plentiful. In general it may be said that basic effusives are characteristic of the range in all localities where rocks are exposed, and that they occur throughout the range is a reasonable assumption. In certain localities the Huronian rocks have been intruded by diorite, diabase, and granite.

The sedimentary rocks of the Middle Huronian may be studied to best advantage in townships 41-42 N, R 1 E, Wisconsin, where many old exploration pits furnish a basis for a definite determination of the series. Natural exposures are limited to a single outcrop of iron formation found at the Michigan mine locality in section 22, T 42 N, R 1 E. At this end of the range the Huronian rocks are apparently thrown

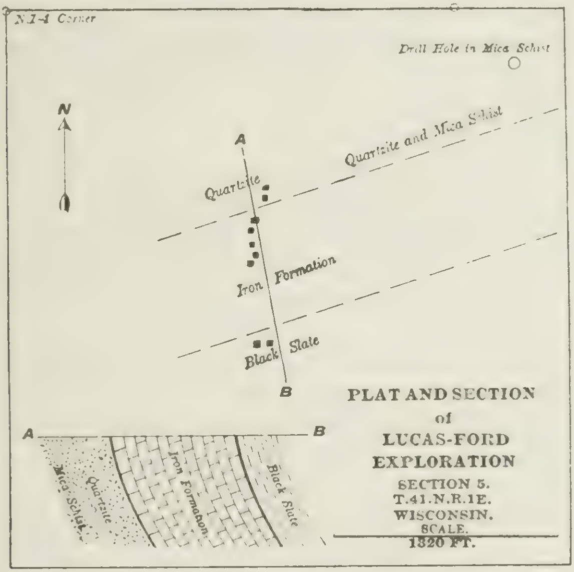


Figure 4.

into a number of close parallel folds whose position is marked by parallel magnetic belts.

From the present information description of a general succession applicable to the entire range is impossible. We will therefore describe in detail the rocks from a number of different localities.

Ford-Lucas Section (Fig. 4). At the Ford-Lucas exploration (NE¼ of the NE¼ and SE¼ of the NE¼, sec. 5, T 41 N, R 1 E, Wisconsin) the Middle Huronian rocks were cross sectioned many years ago by a number of test pits. The material thrown out on the dumps of these pits furnishes abundant evidence of the character of the underlying rocks. The succession is quartzite-iron formation-slate forming the north limb of a syncline, both limbs of which are indicated in the

Whiteside exploration one and three quarters miles east. No other rocks are exposed at this locality. The accompanying figure shows the location of the pits. There are a number of other pits in the vicinity but their dumps give no indication that bed rock was opened in them. No natural exposure of the Middle Huronian sediments is known at this locality.

The *basal quartzite* is exposed in the two most northerly pits while additional information as to its character is furnished by a recent drill hole put down by R. B. Whiteside near the northwest corner of section 4. This hole is reported to have passed through 400 feet of muscovite-quartz schist. The rock exposed in the test pits is a dense, fine grained, faintly banded, gray quartzite through which are scattered numerous small cubes of pyrite. It is composed of quartz, pyrite, and innumerable particles of black dust. The quartz is entirely recrystalline and in thin section is arranged in a finely grained mosaic of roughly hexagonal individuals. Pyrite is plentiful in small cubes, slightly larger than the individual quartz crystals, and the black dust is scattered throughout as inclusions in quartz. Metamorphism has obliterated all traces of clastic texture but the mineral composition and the presence of definite though faint banding admit of no doubt that the rock is an altered sediment. The thickness of this formation is not less than 150 feet and is probably greater than 300 feet.

The *iron formation* is exposed in a number of pits south of the quartzite. In general, it may be described as finely banded, dark gray to black, siliceous amphibole-magnetite schist carrying a little residual carbonate. Narrow bands of brown amphibole and wider bands of rather coarsly crystalline quartz are abundant. The wider, light colored bands are mainly quartz, the magnetite and amphibole being concentrated in the narrower and darker colored layers. The important minerals are quartz, grünerite, and magnetite with subordinate carbonate, (probably siderite) and brown iron oxide. In general, the minerals are arranged in definite layers or bands. The quartz is entirely recrystalline and appears in thin section as a typical interlocking mosaic. The coarser grained bands are nearly pure silica, while those of finer grain contain abúndant magnetite. The amphibole is, in all specimens examined microscopically, grünerite, but it is very probable that the varieties actinolite and commingtonite are present. Grünerite commonly occurs in fairly large individuals oriented parallel to the banding; to a less extent as small twinned individuals and in compact bundles of needles. In the larger grünerite individuals alteration to brown iron oxide occurs along cleavage cracks and around the borders. Many irregular shaped crystals of magnetite are included in grünerite and the contact between the grünerite individuals is often marked by concentration of magnetite and carbonate. Certain bands are made up of small, well formed, twinned crystals of grünerite with considerable magnetite, the latter partly in parallel intergrowth with the former. The grunerite has a well developed parallel alignment.

Unaltered ferruginous chert and cherty iron carbonate are not found in this locality. The formation is highly metamorphic and offers little promise of containing workable bodies of iron ore in the immediate vicinity. The thickness is not less than 650 feet, and probably not more than 700 feet.

The overlying formation, exposed in the two southerly pits, is *soft black spotted slate* that weathers yellow. Under the microscope small, well crystallized, colorless garnets appear imbedded in an exceedingly schistose ground mass which under high magnification is resolved into a felty mass of minute flakes of biotite between which can be dimly seen limpid grains of dull gray quartz and feldspar (?) filled with carbonaceous dust. The quartz and feldspar (?) are barely discernible because of the abundance of the mica and carbonaceous inclusions. The garnets, which give the rock the spotted appearance in hand specimen, are colorless and usually well crystallized. The schistosity curves around them producing a characteristic augen structure.

No data is available upon which to base a determination of the thickness of the slate. In *Fig. 4*, the dip given to the formation in the cross section is entirely theoretical. The drill cores from the hole shown in the NE corner of the section indicate a very steep dip. Inasmuch as the structure in this region, as revealed a short distance east, is probably synclinal, a southerly dip was assumed in constructing this section.

Whiteside Exploration (*Fig. 5*). The Upper Huronian series here apparently forms a syncline with opposite limbs exposed in the exploration pits. The north limb of the syncline is continuous with the Lucas-Ford exploration to the west. The succession at the latter locality is repeated in the Whiteside pits.

The *basal quartzite* so well exposed at the Lucas-Ford locality is represented here by a few large angular fragments of hard, gray, vitreous quartzite thrown out on the dump of the southernmost pit.

The *slate* is almost identical in character with that in section 5. It is a typical, pyritic, black slate.

The *iron formation* is well exposed in the dumps around the old shaft and pit on the north limb and on the dumps of several pits on the south limb of the syncline. On the north limb it is for the most part a rather lean, limonitic chert containing considerable magnetite and a little unaltered iron carbonate. The rock is typically banded, yellowish-brown limonitic bands alternating with other bands composed predominantly of white, grayish-black, and occasionally reddish chert.

Iron amphibole is noticeably absent at this locality. In general, the formation is soft, somewhat porous, and shows no evidence of having been subjected to severe metamorphism but it is lean and shows little concentration of iron oxide.

The formation of the south limb of the fold, so far as known, contrasts sharply with that of the north limb just described. It is an

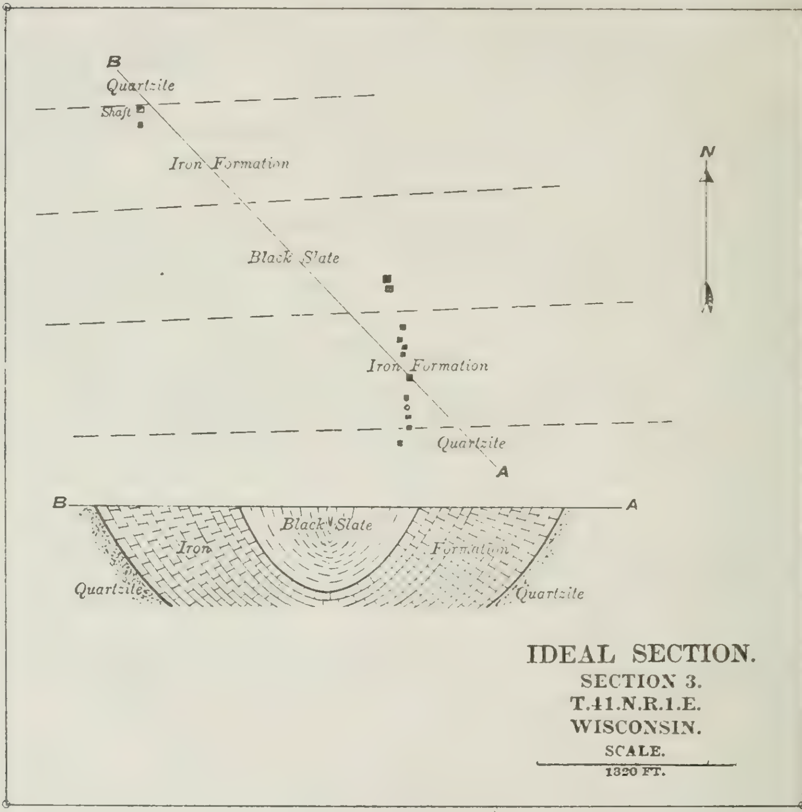


Figure 5.

amphibole magnetite schist similar to that at the Ford-Lucas exploration. The chief minerals are amphibole (mainly grunerite with subordinate actinolite), quartz, magnetite, carbonate and brown iron oxide, the latter apparently the result of surface weathering of the grunerite. It is needless to add that the formation in this vicinity is unpromising from an economic standpoint. The thickness here is apparently the same as at the Ford-Lucas locality, namely, in the neighborbood of 650 feet

The cross section, (*Fig. 5*), is in part ideal. It is probable that the fold is much deeper than represented in the drawing. The boundary between the iron formation and quartzite on the north limb of the syncline is placed just north of the shaft on the basis of statements made by residents of the locality who worked here at the time exploration was active. Such information is not considered reliable.

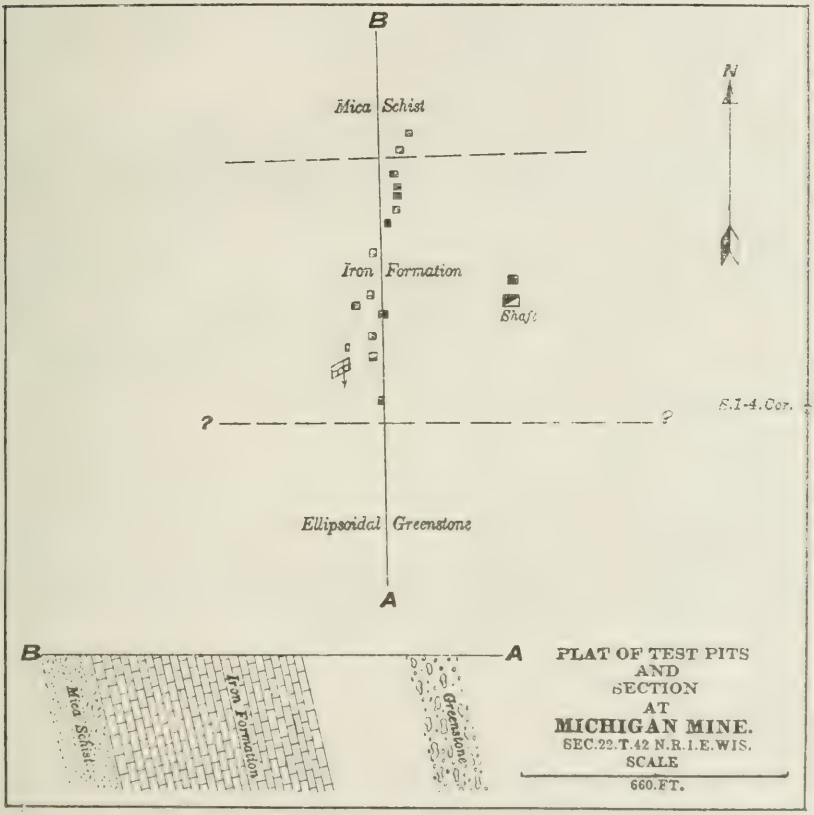


Figure 6.

Michigan Mine. (*Fig. 6.*) The old Michigan mine is located in the SE¼ of the SW¼ of section 22, T 42 N, R 1 E. The workings consist of a number of test pits and a shaft. The dump adjacent to the shaft contains about 2,000 tons of iron formation but none of the other workings show very extensive exploration.

The rock exposed in the northernmost pits is a soft, gray, rather fine grained *muscovite schist* which in thin section is observed to be composed mainly of quartz and muscovite with considerable graphite; accessory minerals are biotite, epidote and hematite. The muscovite, biotite and graphite flakes possess a decided schistose structure, and even the individuals of quartz forming the crystalline mosaic filling the spaces between the micaceous minerals show a tendency toward elongation parallel to the alignment of the muscovite crystals. The epidote seems to have formed after the development of the schistosity as it occurs in fairly large, fully formed crystals whose growth has pushed aside the schistose ground mass. Although no traces of sedimentary structures or textures remain there can be little doubt from consideration of the mineral content, and especially the presence of graphite, that the schist is a metamorphic sediment.

As to the question of the position of the schist with reference to the iron formation no direct evidence is available. The dip of the rocks in this vicinity, as revealed by the single known outcrop of iron formation, is toward the south at an angle of about 85 degrees. If the schist is regarded as belonging to the upper slates, overturned folding is indicated. The presence of graphite in the schist renders it probable that this rock should be placed in the overlying slates rather than in the basal member of the Upper Huronian which is predominantly a hard vitreous quartzite. On the other hand the rocks underlying the iron formation are in places mashed to micaceous schist as shown by the drill holes in section 4, T 41 N, R 1 E.

The *iron formation* is typical, lean, banded "hard ore jasper." In general the bands are white, dark gray or black and occasionally red. The iron is in the form of magnetite and hard blue and specular hematite. Amphibole and chlorite are sparingly developed. It is possible with considerable search to pick up small pieces of ore that contain 60 per cent metallic iron, but in general the formation is lean and cherty. In thin section, quartz, magnetite, hematite and siderite, with occasional needles of amphibole and flakes of chlorite, appear as the constituent minerals.

The thickness of the iron formation is probably in the neighborhood of 650 feet, about the same as at the Whiteside and the Ford-Lucas localities in the township adjacent on the south, although the exact thickness cannot be determined from the pits.

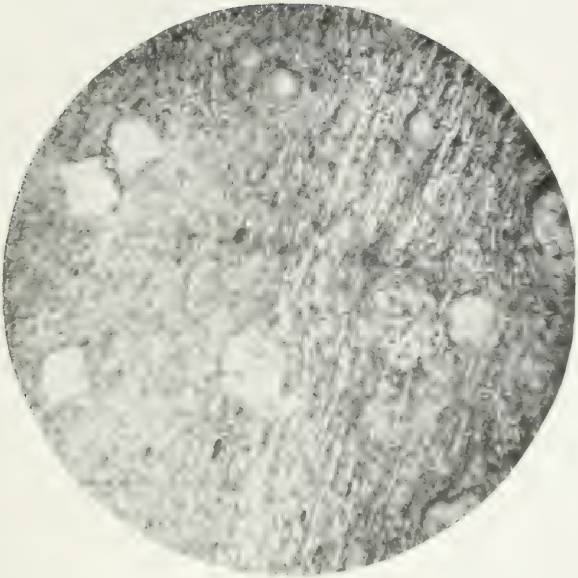
Ellipsoidal greenstone occurs a short distance south of the exploration in section 27. Its relation to the iron formation is unknown. It is probable that effusive greenstone is interbedded in the Middle Huronian series. The petrographic character of these rocks will be considered later.

Broomhandle exploration. In the NW$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 29, T 42 N, R 1 E, there are five pits on the magnetic belt that marks the position of the iron formation at the Michigan mine in section 22. Highly metamorphic, lean, iron formation and a coarse grained, altered

Plate VII.

(A). (Without analizer, X 16). Black slate from test pits of Ford-Lucas exploration, SE¼ of SE¼ of section 5, T. 41 N, R. 1 E., Wisconsin. Secondary garnet imbedded in a schistose groundmass composed of quartz, feldspar (?), carbonaceous material and biotite. Note that the garnet during growth has pushed aside the groundmass.

(B). (Without analizer, X 16). Grünerite-magnetite-schist from drill hole 17, SE¼ of SW¼ of section 26, T. 43 N., R. 3 E., Wisconsin. The section shows only grünerite and quartz but magnetite is abundantly developed in this rock. The concentration of the amphibole in thin bands is well shown.



(A)

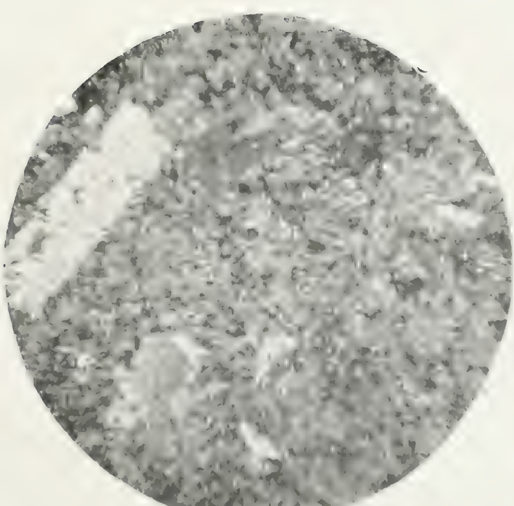
(B)

Plate VIII.

(A). (With analizer, X 16). Altered porphyrite from section 22, T. 42 N., R. 1 E., Wisconsin, near Michigan mine. The plate exhibits a large phenocryst of plagioclase showing granulation and fracturing. The groundmass is a schistose matte of green hornblende needles with scattered grains of epidote and a few irregular patches of magnetite.

(B). (With analizer, X 16). Altered porphyrite from east end of Turtle range near south quarter post, section 27, T. 46 N., R. 41 W., Michigan. The normal composition of this rock is essentially similar to that in (A). The groundmass is coarser grained but is predominantly green hornblende with a small amount of magnetite, epidote, limpid feldspar and quartz. The large phenocrysts are plagioclase.

(A)



(B)

Plate IX.

(A). (Without analizer, X 16). Fine grained hornblende schist from SE¼ of NE¼ of section 33, T. 46 N., R. 41 W., Michigan. This plate shows the appearance of the fine grained hornblende schist of the Turtle range which is regarded as metamorphic basic lava or tuff. Mineralogically, this rock is identical with the groundmass of the altered porphyrite.

(B). (Without analizer, X 16). Altered basic amygdaloidal lava from near the center of section 4, T. 42 N., R. 3 E., Wisconsin. This rock is one of the effusives from the Turtle range west of Mercer, Wisconsin. The amygdaloidal structure is well shown in the figure. The filling is epidote, zoisite and quartz. The groundmass is largely composed of compact needles of green hornblende.

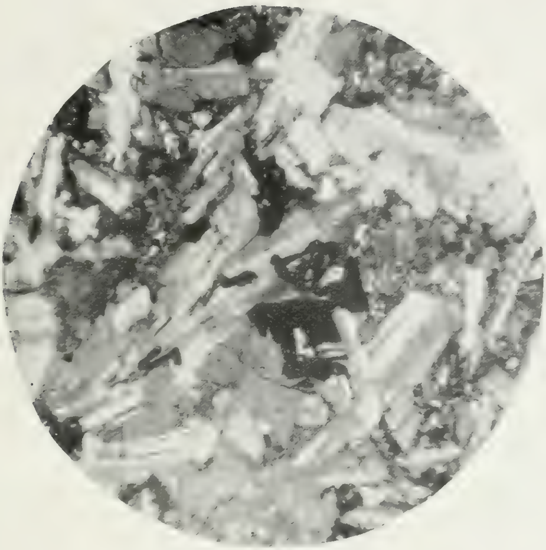
(A)

(B)

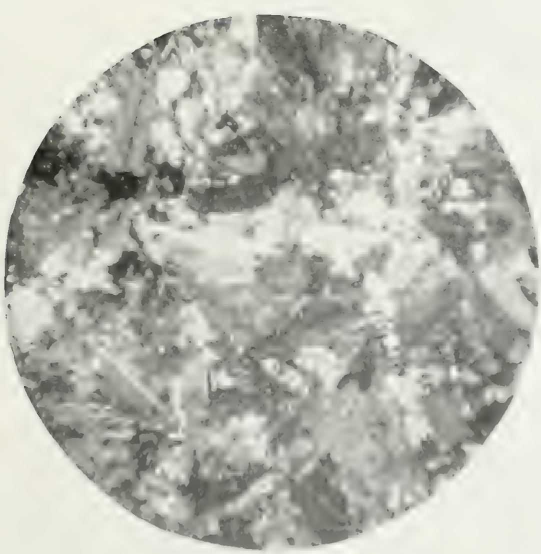
Plate X.

(A). (With analizer, X 16). Diabase from dike cutting basic lavas in the NW¼ of SW¼ of section 34, T. 43 N., R. 3 E., Wisconsin. This plate is introduced to show the extremely fresh appearance of the diabase dikes found on the Turtle and Marenisco ranges. Minerals present are plagioclase, augite, magnetite and olivine. The olivine is generally more or less altered to serpentine but the other minerals are fresh and show only incipient alteration.

(B). (With analizer, X 16). Altered diabase in the SW¼ of section 15, T. 42 N., R. 2 E., Wisconsin. This is one of the more readily recognizable massive greenstones abundant on the Turtle and Marenisco ranges. Contrast the appearance of this rock with the diabase of (A). Consideration of the mineral composition of the altered diabase shows that it was probably identical with that in (A), with the exception that the rock in (B) is apparently lacking in olivine. It is made up of altered feldspar, the original lath shapes of which are barely discernible, magnetite, leucoxine and green hornblende, the latter probably derived from augite although no trace of pyroxene now remains.



(A)



(B)

diorite appear on the dumps. The formation is mainly dark gray, recrystallized chert with occasional bands containing considerable magnetite and a few narrow bands of green amphibole. The major part of the dump material is dull gray chert. In thin section, banded rocks of the iron formation disclose the presence of quartz and magnetite, with many small needles of actinolite, a few flakes of chlorite, specks of hematite and small irregular areas of carbonate and pyrite. The quartz constitutes a very fine, crystalline mosaic and in places shows the irregular grains and suture lines characteristic of chert. Magnetite is roughly concentrated in streaks and bands and associated with this mineral are minute needles of actinolite usually visible only under high magnification.

Closely associated with the iron formation in this locality is a coarse grained, *massive greenstone*. One of the pits shows both iron formation and greenstone on the dump, while the two south pits are in greenstone alone. The greenstone is composed mainly of large individuals of allotriomorphic, ragged, green hornblende. The interstitial material is mainly secondary albite, quartz, epidote, zoisite, magnetite-leucoxine, and occasional flakes of biotite. Obscure traces of large striated plagioclase are still to be seen, but the original textures and minerals have been largely destroyed by alteration.

The highly metamorphic character of the iron formation in this locality together with the sudden termination of the magnetic belt just west of the pits is evidence that the greenstone is intrusive in the iron formation and perhaps representative of a large body of igneous material which cuts out the Huronian rocks west of this locality.

Mercer Section. Proceeding northeast along the Turtle range from townships 42 and 41 N, R 1 E, Wisconsin, nothing is known regarding the character of the Middle Huronian sediments except the data obtained from recent diamond drilling. A number of drill holes were put down by the F. I. Carpenter syndicate in the vicinity of Mercer, T 43 N, R 3 E, Wisconsin. At this locality the Turtle range is marked by two belts of magnetic attraction separated by narrow strips of normal territory.

Diamond drill hole No. 17 is located on the maximum magnetic line of the south belt a short distance north and west of the south quarter corner of section 26, T 43 N, R 3 E. After passing through 174 feet of overburden this hole was ledged in a steeply dipping banded rock showing wider bands of light gray quartz alternating with narrower bands of light brown amphibole and others nearly black in color containing magnetite. In thin section the rock appears to be composed of quartz, magnetite, grunerite and a small amount of carbonate. The minerals are arranged in bands, some consisting of quartz alone, some of quartz and magnetite, and others of grunerite and quartz with subordinate magnetite and a little carbonate. The grunerite fibers in the center of the grunerite bands are oriented parallel to the banding but on the borders the amphibole needles are at right angles to the banding and penetrate into the adjacent quartz grains. The larger crystals of grunerite are beautifully twinned and generally idiomorphic in cross section The rock is a *grunerite-magnetite-schist* typical of highly metamorphic iron formations. Analysis of drill core at a depth of 208 feet shows Fe., 29.1 per cent.

Drill hole No. 19 on the maximum line of the north belt in the NW$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 26, T 43 N, R 3 E, was discontinued after penetrating 22 feet of rock. After passing through about one and one-half feet of biotite-hornblende schist the drill entered a dark colored, cherty rock containing reddish garnet, green fibrous amphibole, and pyrite in crystals of sufficient size to be macroscopically visible. Toward the bottom of the hole the rock has a pronounced banding caused by alternating layers of pure black chert and cherty bands containing amphibole and garnet. Magnetite is present in sufficient quantity to affect the magnetic needle although not developed in crystals of sufficient size to be macroscopically visible

A thin section cut from one of the amphibole-garnet bands exhibits a fine grained, cherty mass of quartz in which the other minerals are embedded. Amphibole, biotite and large irregular crystals of garnet are scattered throughout the rock. Small grains of magnetite are included in the garnet and larger amphibole crystals. The amphibole is mainly dark green and strongly pleochroic but associated with it is a colorless amphibole. In thin section the latter commonly forms a light border around the edges of the former with which it is in perfect optical orientation, a feature which is also retained when, less commonly, the two varieties are in parallel intergrowth. Finally, both the colorless and green varieties occur in separate crystals, the latter in greater abundance. A very small optic angle giving an interference figure nearly uniaxial in character is a peculiarity of the green hornblende. The optical sign is negative. The colorless amphibole has a large optic angle and is apparently positive. Where it is not associated with the green hornblende it possesses twinning characteristic of grunerite.

That this rock is a metamorphic phase of the iron formation is apparent from its cherty character, abundance of magnetite and iron amphibole, and pronounced banding. The presence of garnet is interesting. A somewhat similar type of alteration, described by Leith, occurs in the Biwabic formation of the Mesaba range at the contact with the Embarrass granite* and Van Hise, Bailey and Smyth describe

*Leith, C. K. Monograph No. 43, U. S. Geological Survey, p. 162.

similar occurrences in the Negaunee iron formation of the Marquette range at the Republic and Magnetic mines**. At the latter locality grunerite and green hornblende occur in parallel intergrowth and biotite and garnet are abundantly developed in the iron formation adjacent to the greenstones and at low horizons in the formation.

Four other drill holes in this vicinity penetrated altered basic intrusives belonging to the diorite and diabase family. The highly metamorphic iron formation found on both belts renders it very probable that the latter are intrusive in the Huronian series at this locality.

About three miles southwest of Mercer a drill hole (No. 14) located on the north border of the magnetic belt passing through section 11, T 42 N, R 3 E, penetrated a slate formation in the form of a garnetiferous, pyritic and graphitic schist. In hand specimen and in thin section this rock is very similar to the slate at the Ford-Lucas and Whiteside localities. In mineral composition the two rocks are identical.

Winegar Section. (*Fig. 7*). The Turtle range was recently cross-sectioned in the vicinity of Winegar, Wisconsin, T 44 N, R 6 E, by eight diamond drill holes. The section indicates a synclinal fold carrying Lower Huronian quartzite and dolomite on the opposite flanks with the Middle Huronian slate-iron formation series occupying the middle or trough. The quartzite and dolomite have been described above.

In general, the Middle Huronian has suffered extreme metamorphism and there is abundant evidence in the drill cores that igneous intrusion has played an important role in this connection. As near as it is possible to judge from the drilling the iron formation is underlain and perhaps in part interbedded with badly altered slate.

Hole 39 penetrated 34 feet of *dark gray, fine grained carbonaceous schist* cut by many stringers of intrusive granitic and pegmatitic material, especially in the upper 10 feet. The contact between the schist and the granite is marked by narrow veins and seams of pyrite. The cleavage approaches in perfection that of slate and in part of the core a well defined narrow banding is exhibited. Biotite is the most abundant mineral. The interstices between the biotite crystals are filled with a dull gray, weakly polarizing substance not separable even under the microscope. It is probably secondary quartz and feldspar. The only other noticeable features are long, lens shaped bodies of pyrite oriented parallel to the schistosity and the occasional development of large porphyritic chlorite individuals at variance with the schistosity. The latter are rich in inclusions of pyrite and carbonaceous material. As will be shown later, the Middle (Animikie) Huronian series at the Banner locality, about five miles northeast, is represented by iron formation, slightly anamorphosed, underlain by a considerable thickness of black

**Van Hise, C. R., Bailey, W. I.; and Smyth, H. L. U. S. G. S. Monograph No. 28, pp. 390-91.

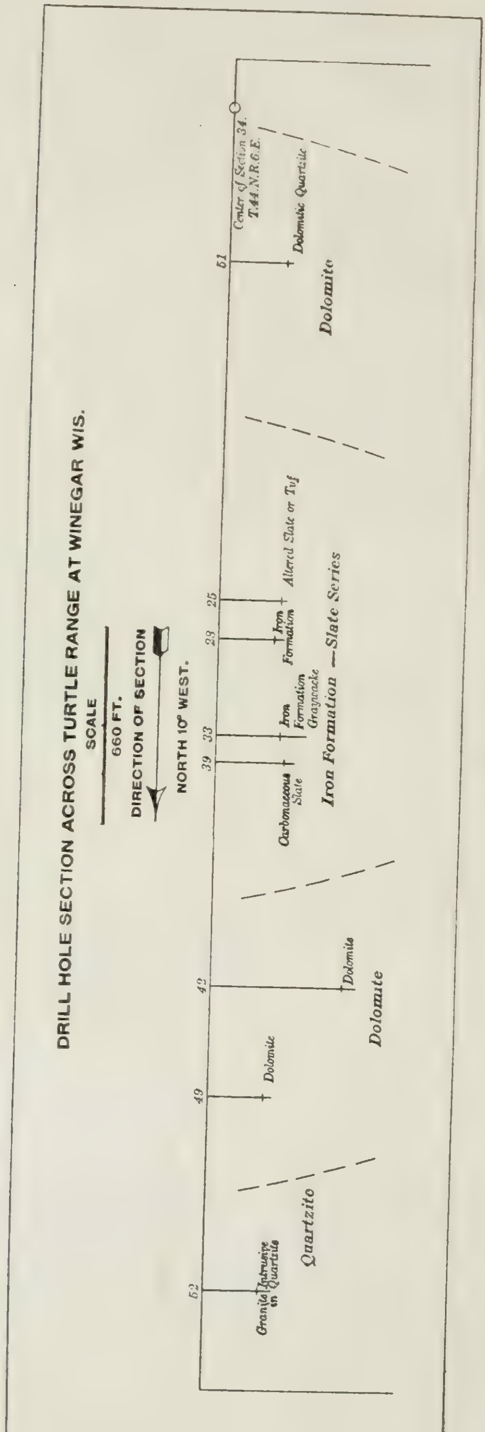

DRILL HOLE SECTION ACROSS TURTLE RANGE AT WINEGAR WIS.
SCALE
660 FT.
DIRECTION OF SECTION
NORTH 10° WEST.
Center of Section 34.
T.44.N.R.6.E.
51
Dolomitic Quartzite
Dolomite
25
28
33
39
Altered Slate or Tuf
Iron Formation
Iron Formation
Graywacke
Carbonaceous Slate
Iron Formation —Slate Series
42
Dolomite
Dolomite
49
Dolomite
52
Granite Intrusive in Quartzite
Quartzite

Figure 7

slate. There can be no doubt that the carbonaceous schist found in hole 39 is an altered sediment although original textures and structures are now largely destroyed. From a consideration of its mineral composition and its position with reference to the holes in dolomite and in iron formation it is probable that this rock is to be correlated with the slate below the iron formation at the Banner exploration.

Hole 33, located about 100 paces south of No. 39 encountered rock at 215 feet and drilling was continued to a depth of 307 feet. The core from 215 to 239 feet is fine grained, dark colored graywacke. Here and there the rock has a silky lustre due to local development of muscovite. Microscopic examination reveals small rounded and angular grains of quartz embedded in a schistose ground mass of micaceous minerals, mainly chlorite, biotite, and muscovite. Accessory minerals are epidote, black dust (carbonaceous?), a few small garnets and octahedrons of magnetite. The core from 239-244 feet is lean ferruginous chert made up of alternating bands of various shades of gray and to less extent red or green. The iron is in the form of magnetite with subordinate hematite and pyrite.

The lean iron formation described above grades downward into a dark, greenish black, garnetiferous schist containing quartz, pyrite, garnet, biotite, and considerable black dust, probably carbonaceous material. In thin section most of the garnets are altered around the edges to a fine grained, green colored matte. Under high magnification this green matte appears to be a chaotic assemblage of innumerable minute doubly refracting needles of a mineral resembling serpentine. The origin of this rock is indeterminate, but the presence of carbonaceous dust, the apparent absence of feldspar, either original or secondary, and the fact that the rock from 215-244 feet is plainly sedimentary are strong presumptive evidence that the schist from 244 feet downward is also a sediment.

Hole 28, about 250 paces south of hole No. 33, penetrates 26 feet of typical, banded, biotitic-sideritic-magnetitic-schist cut by a dike of fine grained diabase. The constituent minerals in the order of their relative abundance are quartz, biotite, magnetite, siderite, pyrite, chlorite, sericite, and amphibole. The carbonate in this rock was determined as siderite by microchemical tests. Although in some respects this rock is peculiar, when the abundance of iron is taken into consideration there can be no doubt that it belongs to the iron bearing series. The presence of considerable biotite and chlorite and the almost total lack of typical iron amphiboles such as grunerite or actinolite may perhaps be accounted for on the theory that the iron formation at this locality was originally deposited with considerable intermixed clastic material. No trace of clastic textures now remain, but in mineral composition this rock is very similar to the iron formation largely intermixed with fragmental grains of quartz and feldspar exposed south of the Marenisco station.

Hole 25, about 130 paces south of No. 28, cut 15 feet of dark, greenish colored, fine grained schist, full of narrow wavy bands or veins of white quartz. Locally there is an abundant development of orthoclase and pyrite in the quartz bands and this suggests the idea that the quartz bands are pegmatitic material injected parallel to the schistosity. The greenschist is, in general, very fine grained and near the bottom of the hole is characterized by abundant development of light red garnets. Near the top of the hole the schist contains many small oval shaped spots of lighter green color than the ground mass and oriented parallel to the schistosity. Under the microscope these green spots appear as large crystals of green hornblende embedded in a fine grained ground mass consisting of biotite, feldspar, and quartz, and a few specks of leucoxine; the large hornblende individuals are full of small inclusions of limpid feldspar and quartz. Small grains of limpid feldspar and quartz also fill the spaces between the flakes of biotite which is the most abundant mineral. The number, distribution and arrangement of the inclusions of quartz and feldspar in the large green hornblende crystals simulate exactly their distribution in the ground mass and under crossed nicols there is little difference in appearance between the large hornblende crystals and the micaceous ground mass. Close examination reveals, however, that whereas in the ground mass the biotite is made up of many small individual flakes with nearly simultaneous extinction due to crystallographic parallelism, each green spot represents a large individual of green hornblende. The alignment of the hornblende and biotite and the abundance of ferro-magnesian mineral makes the thin sections nearly dark when the direction of schistosity is parallel to one of the cross hairs of the microscope. The small limpid feldspar grains are more abundant than quartz and show incipient alteration to sericite. In general, both the quartz and feldspar grains are arranged with their longer dimensions parallel to the schistosity. A few rounded grains of both minerals are to be seen, but they are of small size and fit perfectly into the mosaic. In addition to the minerals described, magnetite, pyrite, epidote, and rutile are present in small amounts. This rock is now in the most complete sense a crystalline schist and no direct evidence of its original character may be obtained. The presence of abundant basic material and particularly the green hornblende are somewhat suggestive of an igneous rock, perhaps of the nature of a tuff. In some respects it resembles the "spilosites" produced by contact metamorphism of the Mansfield slate by intrusion of dolerite*.

The interpretation placed upon the data obtained from drilling at Winegar may be seen by reference to *Fig. 7*. The highly metamorphic character of the Middle Huronian adds greatly to the difficulty of interpretation and no definite succession can be determined with certainty.

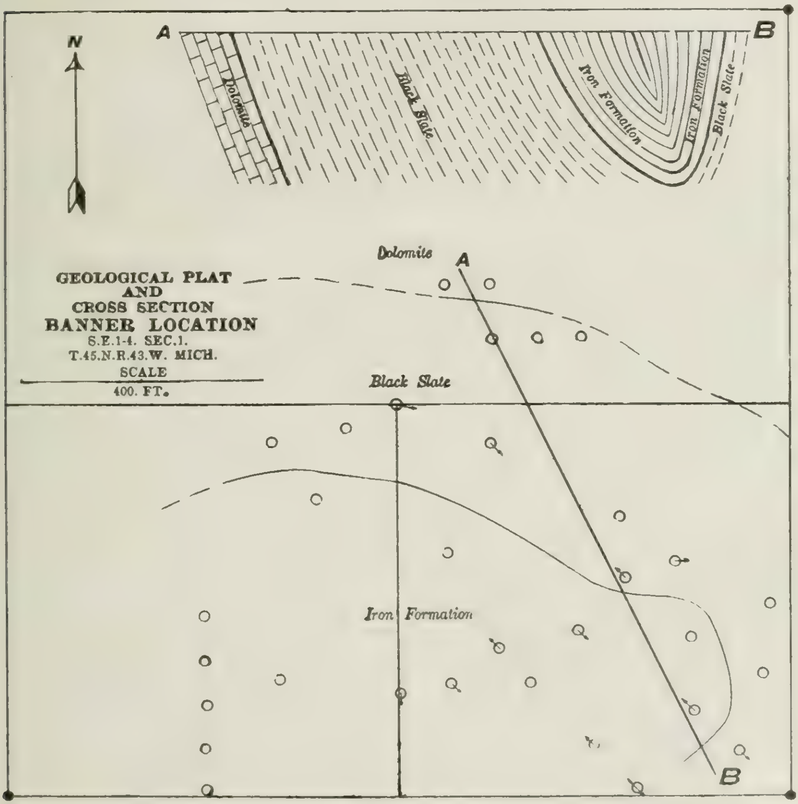


Figure 8.

It seems highly probable that the deposition of the iron bearing rocks was accompanied by a large intermixture of mud and probably volcanic tuff. Later the rocks were folded and intruded by both acid and basic igneous material with the production of a complex series of schists, the origin of parts of which are in many cases extremely difficult of determination.

Banner Location. (*Fig. 8*). Recent drilling by the E. J. Longyear Co. in the SE¼ of section 1, T 45 N, R 43 W, in the neighborhood of

*J. M. Clements, H. L. Smyth, and W. S. Bailey, Mon. 36, U. S. Geological Survey, p. 206, plate 37, fig. A.

an old shaft and group of test pits known as the Banner mine, has given a very clear idea of the character and succession of the Huronian rocks of this portion of the Turtle range. At this locality the rocks are much less metamorphic than any heretofore described. As may be seen on the accompanying geological maps and sections the Huronian series occupies a southwestward pitching synclinal trough.

Dolomite, the lowermost known member, is overlain by *gray schist,* apparently not less than 150 feet thick. Between the schist and *iron formation* is a thickness of not less than 500 feet of *black pyritic slate.* The iron formation which occupies the center of the trough, is probably from 700 to 1000 feet thick. It is, for the most part, rich ferruginous chert or "soft ore jasper." Near its southern margin it contains some hard blue hematite and unaltered iron carbonate. In places the iron formation carries ore bodies, but, so far as known, these are too small to warrant mining.

The succession here may be compared with that at Winegar. Dolomite appears to underlie a slate-iron formation series in both localities. At Winegar there is apparently considerable mud and volcanic debris in the iron bearing rocks but at the Banner exploration they are comparatively free from intermixed detrital material. The two localities are connected by a continuous magnetic belt and it is probable that the two successions are representative of one and the same series.

IGNEOUS ROCKS.

With the exception of the single outcrop of iron formation at the Michigan mine the known natural exposures on the Turtle range are igneous, and comprise both intrusives and extrusives.

Intrusives. In general, the intrusives are basic in composition although granite occurs in drill holes at Winegar. At the Broomhandle exploration near the west end of the range, greenstone is closely associated with and probably intrusive in the iron formation. Northwest from this locality, on the rock ridges southwest of Mercer, dikes of diabase occur in association with effusive lavas. The intrusives are highly altered and are composed mainly of large individuals of sedgy green hornblende magnetite-leucoxine and alteration products of feldspar such as epidote, quartz, ziosite, and limpid albite. In most instances the microscope reveals some traces of original, lathshaped plagioclase. In addition to the altered types, dykes of fresh diabase are occasionally seen. The fresh diabase is characterized by its content of primary augite.

Two drill holes near Mercer penetrate fresh diabase, a third, massive greenstone conforming more closely to altered diorite.

Granite and greenstone apparently intrude both the Middle and Lower Huronian series at Winegar.

Extrusives. The most abundant rock outcrops on the Turtle range are effusive greenstone. Rocks of this type are plentifully exposed in Ts 46-45 N, R 41 W, Michigan; and in T 42 N, Rs 1, 2, 3 E, and T 43 N, R 3 E, Wisconsin.

At the former locality, the magnetic belt marking the position of the Turtle range is closely associated with porphyritic green schist and a number of exposures of ellipsoidal greenstone occur a short distance south of the belt in section 3, T 46 N, R 41 W. Associated with the porphyrites and ellipsoidal greenstones are fine grained green schists and aphanitic greenstone.

The greenstone porphyrites were found on several traverses just south of the maximum magnetic line. They are light green, fine grained and exhibit on weathered surfaces small white phenocrysts of feldspar, generally rounded but occasionally lathshaped or roughly rectangular in outline. The phenocrysts are in general from 1-32 to 1-4 of an inch in diameter, although larger ones are occasionally found. On fresh fractured surfaces the feldspar phenocrysts are not easily seen. Schistose structure with an average strike of N 60° E and southerly dips is conspicuous.

Microscopic examination shows that these rocks are very similar in many respects to the lavas in the north portion of this township described in connection with the Marenisco range. They are, however, more basic in composition. Phenocrysts of plagioclase are embedded in the ground mass consisting mainly of pale green weakly pleochroic needles of amphibole. Associated with this mineral are lesser amounts of magnetite, pyrite, limpid feldspar carbonate and probably quartz. Occasionally the main mineral in the ground mass is chlorite instead of amphibole. Epidote in small granules is rather common in the chlorite areas. In one observation the ground mass has the appearance of whorls suggestive of an original perlitic structure. In general, the needles of amphibole follow the periphery of the feldspar phenocrysts but occasionally penetrate them producing a micropoecilitic structure. The magnetite is scattered throughout the ground mass in irregular patches and is apparently unassociated with leucoxine although rutile is a common associate. The phenocrysts of plagioclase are in general saussuritized; less commonly they are altered to biotite and muscovite. The twinning lamellae are practically destroyed but the small angle of the feldspar phenocrysts in general indicates a rather acid plagioclase, so far as we can determine, approaching oligoclase in composition. The green porphyrite appears to have been, originally, an andesite.

Ellipsoidal greenstones occur just south of the north line in section 3, T 45 N, R 41 W. The outlines of the ellipsoids are in some cases plainly discernible, but in the majority of instances they are imperfect and only faintly suggested. Some parts of the rock are made up almost entirely of the ellipsoidal forms resting in material having the same apparent composition as the ellipsoids themselves. The ellipsoids vary in size from a few inches up to four feet in major axis. The longer ones lie in the general direction of regional schistosity. The outlines of the ellipsoids are marked by the deflection of the lines of schistosity around them, the matrix between the ellipsoids being plainly more schistose than the rock within the ellipsoidal boundaries. Amygdaloids occur in outcrops close to the ellipsoidal greenstones. No minerals are recognizable with the naked eye in either the ellipsoidal or amygdaloidal greenstone. The entire series has been intensely metamorphosed with a development of schistosity striking about N 70° E and dipping south.

Closely associated with the rocks described above are *fine grained, green schists* which under the microscope appear almost identical in mineral composition with the ground mass of the greenstone porphyrite which is composed of small green hornblende needles. Accessory minerals are feldspar, quartz, epidote, carbonate and magnetite-leucoxine.

Similar fine grained hornblende schists are found in connection with the effusives southwest of Mercer, Wisconsin. These will be described in greater detail in connection with that locality.

From the vicinity of Mercer, Wisconsin, to the southeastern part of T 43 N, R 3 E, to section 9, T 42 N, R 2 E, there are many exposures of greenstone and greenschist on a series of rather pronounced ridges having a general strike parallel to the magnetic belts. For the most part the rocks are effusive lavas of agglomeratic and occasionally amygdaloidal structures and porphyritic textures. Associated with the effusives there are lesser amounts of basic intrusives, mainly diabase.

The agglomeratic structures are not abundantly developed, but in places they are a conspicuous feature of the exposures. In section 34, T 43 N, R 3 E, and in section 4, T 42 N, R 3 E, this structure is beautifully developed in many exposures. At the former locality, near the center of the section the outcrops present the appearance of typical breccia. Angular and rounded fragments of fine grained greenstone, ranging from less than an inch to a foot or more in diameter, are embedded in a dark green, schistose matrix generally of the same apparent mineral composition of the ground mass but of coarser grain. However, the composition of the matrix is somewhat variable and at one locality it appears to be mainly calcite. In section 4 many of the fragments of the breccia are amygdaloidal but an exposure in section 32, T 43 N, R 3 E, is characterized by a porphyritic texture. At the latter locality the fragments are of large size and in some cases oval or ellipsoidal in outline. Some of the ellipsoidal boulders measure two or three feet in the longer dimensions. The material which cements them together is, for the most part, coarse grained, white, vein quartz with considerable feldspar. In some respects the structure of the greenstone at this locality resembles the ellipsoidal structure described by Clements* as characteristic of the Ely greenstones of the Vermilion district of Minnesota. However, in the Vermilion district the ellipsoids are set in a matrix described as not greatly different from the greenstone itself, whereas in the present case the matrix is radically dissimilar. Porphyritic texture is a very prominent feature of most of the outcrops of greenstone. The agglomeratic structures are only occasionally seen. Closely associated with the porphyritic types are fine grained aphanitic greenstones and green schists occasionally exhibiting amygdaloidal structures. They resemble in texture the ground mass of the porphyritic varieties and in many cases are almost identical in mineral composition. In a single exposure the rock may change from porphyritic to non-porphyritic and there is no doubt that these fine grained schists and aphanitic greenstones are basic lavas differing but little in composition from the porphyritic varieties. Both types of rock exhibit in places a well developed schistosity striking about N 60° E.

The *porphyritic greenstones* are in many respects similar to those already described but are, in general, more basic in composition. They are composed mainly of phenocrysts of highly altered plagioclase embedded in a ground mass of small, pale green, weakly pleochroic needles of green hornblende. The intensity of pleochroism is apparently governed by the size of the individual crystals. The smaller crystals are very weakly pleochroic, but this phenomenon is strongly developed in the larger ones. The ground mass also contains secondary unstriated plagioclase and probably quartz, many scattered grains of epidote, and considerable magnetite with associated leucoxine. Small patches of carbonate, pyrite, and occasional crystals of rutile and brookite are present in some specimens. The phenocrysts of feldspar most commonly show alteration to a coarse grained mosaic of quartz, albite and biotite. The alteration is rarely complete; as a rule much of the original mineral remains. Saussuritization and sericitization of the feldspar is less often observed. Granulation around the edges of the crystals is a common feature. In the schistose varieties the phenocrysts exhibit only partial parallel orientation, some of them lying with their major axes at right angles to the schistosity in which position many of them are completely fractured and broken in halves cemented

*Clements, J. Morgan. Vermilion Iron Bearing District. Monograph 45, U. S. Geological Survey.

by a coarse crystallization of secondary quartz and albite. The hornblende needles of the ground mass are oriented in all directions in the massive types while in the schistose varieties they exhibit a perfect parallelism.

The plagioclase phenocrysts are too highly altered for exact determination by optical methods, but the prevailing alteration products and a rather large extinction angle shown by the remnants of the original crystals are indicative of a basic composition, which, in consideration with the basic character of the ground mass, points to an original composition near that of andesite.

The microscope readily reveals the effusive nature of the *aphanitic non-schistose greenstones*, especially of the fresher types. Traces of small lathshaped feldspars and the presence of serpentine indicates that the rock is basalt, probably olivine-bearing in phases characterized by serpentine. Even the fresher basalts are now largely composed of secondary products of which green hornblende feldspar and quartz are the most important. Magnetite, epidote, zoisite, carbonate, chlorite, apatite, rutile, pyrite and sericite are present in considerable quantity. The occurrence of the first named three is practically universal, of the others sporadic. Magnetite, as usual, is generally coated with leucoxine.

The more altered aphanitic greenstones are characterized by a large amount of amphibole and absence of all traces of original structures and textures except where they are amygdaloidal. Their general character is almost identical with the ground mass of the altered andesites. In some instances the hornblende individuals are slightly larger and more pleochroic than ordinarily in the porphyrites.

Amygdules may be observed in rocks of this type in at least two localities. The outcrops near the center of section 4, T 42 N, R 3 E, exhibits the best development of this structure. The rock here is a dark green, aphanitic greenstone showing many small white amygdules from 1-20 to 1-10 of an inch in size. In thin section the vesicular filling appears to be coarse grained interlocking crystals of zoisite, epidote and quartz. The matrix of this rock is identical with that of the rocks just described.

By parallel orientation of the hornblende the rocks pass into green schists which in mineral composition do not differ from the more altered massive variety. As a rule they are coarser grained, but ordinarily the only difference consists in the parallel orientation of the amphibole fibres. In the schistose varieties no traces of original minerals, structures or textures are left, and were these rocks found apart from the less altered phases it would be impossible to prove their origin from basic lavas.

Ellipsoidal lavas are exposed in sections 27 and 23, T 42 N, R 1 E.

The outcrops in section 23 are also characterized by the parallel alignment of the ellipsoids. However, the rock itself possesses no parallel orientation of the constituent minerals and therefore cannot be correctly termed a schist. Microscopic examination indicates that the rock is an altered andesite.

The close association of the effusive greenstones with the magnetic belt is characteristic wherever they are exposed. In many cases the greenstone forms long low ridges parallel to and lying just in the outside limits or immediately north or south of the belts of attraction. In other cases, notably from Mercer northwestward, the greenstone occupies non-magnetic territory between the areas of magnetic attraction. At the Michigan mine the greenstone occurs just south of the iron formation and a mile east. Exposures of this rock are immediately north of the belt marking the position of the iron bearing formation.

No contacts between the greenstone and the sedimentaries are known anywhere on the range but the distribution of the greenstone and its close association with the magnetic belts marking the position of the Middle Huronian (Animikie) iron formation amply justify, in the absence of definite proof to the contrary, the conclusion that the effusives are flows interbedded in the Huronian series.

CHAPTER VI.

GEOLOGY OF THE MANITOWISH RANGE.

R. C. ALLEN AND L. P. BARRETT.

The Manitowish range extends from Watersmeet, Michigan, southwest into T 41 N, R 2 E, Wisconsin, a distance of approximately 55 miles. Its position is marked by a series of weak parallel magnetic belts although locally, as in the vicinity of Watersmeet, strong magnetism is characteristic. In general the magnetic belts are narrow but in some localities they exceed a mile in width. This is true of the belt of strong magnetism near Watersmeet.

The region is heavily drift covered and aside from a number of exposures of a peculiar kyanite-mica schist in the southwest portion of T 42 N, R 4 E, Wisconsin, only three outcrops are known. Diamond drilling in a number of localities by the F. I. Carpenter syndicate shows clearly the general characteristics of the rocks in Wisconsin. In Michigan the nature of the rocks underlying the Manitowish magnetic belts may only be surmised.

Both the outcrops and drill cores exhibit coarse grained schists and gneisses and granite. At no locality is it possible to work out a succession of sedimentary formations and in fact it is extremely difficult in many cases to determine even a close approximation to the character of the original rock from which the crystalline schists were derived. It seems perfectly clear that the Manitowish rocks have been metamorphosed to a degree more extreme than that of any other known range or considerable area in the Lake Superior country. There is ample evidence that this intense metamorphism is due to the intrusion of granite on a grand scale. The facts seem to be explainable only on the theory of sub-crustal fusion, i. e. the original sediments have been completely engulfed and assimilated by the intruding magmas, the resultant schists and gneisses deriving their constituents in part from the magma and in part from the fused sediments.

Owing to their limited number the outcrops and the drill records will be discussed in detail and such conclusions drawn as seem warranted from the meager facts.

Granite is exposed at two localities, viz., in sections 34 and 35, T 43 N, R 7 E, Wisconsin. In both localities the rock is light gray biotite granite cut by many pegmatite veins, the latter showing in places well developed graphic intergrowths of quartz and feldspar. The granite is composed of orthoclase, quartz, biotite, muscovite, sericite, apatite and ferrite. These rocks differ from the granites previously described in connection with the other ranges in the absence of microcline. Under the microscope the larger minerals show characteristic granulation and the feldspar has undergone considerable alteration around the edges, although the centers of the crystals are usually very fresh. The exposures lie a little south of the magnetic belts of the Manitowish range but they are probably to be correlated with the great mass of granite intrusive into the sediments of the Manitowish range and the Vieux Desert-Conover district.

The only other exposures on the Manitowish range are *coarse grained crystalline schists and gneisses* marked by an abundant development of biotite, garnet and kyanite. In sections 28, 29, 31 and 33, T 42 N R 4 E, Wisconsin, there are a number of outcrops of these rocks. In section 13, T 42 N, R 5 E, there is a doubtful exposure of the gneiss on the narrows between Spider and Island lakes. At this locality there are groups of large angular boulders and several large blocks of gneiss that possess a common strike of schistosity of about N 70° E. The blocks may be in place. It is certain that none of the material has been transported any great distance.

The rocks in these outcrops are coarse grained and vary from light gray to grayish black; a bluish tinge is noticeable wherever kyanite is abundant. The kyanite is more resistive to weathering than the other minerals and stands out in prominent relief. Gneissose structure, marked by alternate layers of slightly different texture or mineral composition, is nearly always present. In all of the larger outcrops contortion of the gneissose bands is a conspicuous feature. The gneiss is cut by innumerable pegmatite dykes and stringers and veins of quartz.

The chief minerals of the gneiss are quartz, biotite, garnet, kyanite and plagioclase. Muscovite, magnetite, zircon, rutile, apatite, chlorite and pyrite are of subordinate importance. Quartz, biotite, garnet and kyanite are easily recognized in hand specimen, but the other minerals are usually detected only under the microscope. The coarser grained bands are composed mainly of quartz, biotite, kyanite and garnet; the finer grained layers lack the kyanite and usually show a considerable development of feldspar. The texture is very coarse and thoroughly crystalline but the only minerals which exhibit idiomorphic forms are kyanite, apatite and in some instances garnet and pyrite. Quartz is the most abundant mineral and, in larger individuals, exhibits abundant strain shadows and inclusions of liquid and gas. Biotite is the second most important mineral and is deep brown and strongly pleochroic except where bleaching accompanied by separation of magnetite has taken place. The garnets are light brown or red in hand specimen, colorless in thin section. Good crystal development is rare and they are commonly rounded or irregular in outline. The kyanite crystals show the characteristic long development and good crystal form in the prism zone. The individuals average one half inch in length parallel to the C axis and shows no tendency to orientation in the plane of schistosity or in any other plane. Both the garnet and kyanite are filled with inclusions of quartz, biotite and magnetite; this, together with lack of orientation, is evidence that these minerals formed under conditions of static metamorphism after the crystallization of the other minerals had taken place. Plagioclase is the common feldspar and occurs in considerable abundance in the finer grained kyanite-free bands. It is in all cases very fresh, showing only slight alteration. In composition it appears to be oligoclase and albite-oligoclase.

The main clue to the origin of the biotitic, garnetiferous, kyanitic gneiss lies in its mineral composition. The universal presence of the aluminum silicate, kyanite, is the most suggestive feature. In discussing the occurrence of the aluminum silicate group Van Hise* says: "The special homes of the aluminum-silicate minerals are the metamorphosed argillaceous sedimentary rocks. As is well known, kaolin is one of the chief constituents of such rocks, and doubtless it is from this mineral, in larger part under deep seated conditions, that the aluminum silicates are formed." The same author in discussing the criteria to be used in discriminating between the metamorphic igneous and sedimentary rocks, says,† "Staurolite and andalusite, sillimanite and cyanite are very characteristic minerals. Therefore, where certain single minerals are dominant in the schists and gneisses it seems to be a fairly safe conclusion that the rocks are sedimentary in origin." The mineral kyanite, because it has the highest specific gravity of the aluminum silicate group, is significant also of the most profound anamorphism and the universal presence of this mineral coupled with the entire absence of andalusite or sillimanite is a measure of the intensity and character of the metamorphism prevalent on the Manitowish range. The regional schistosity and contortion of the gneissose bands together with the occurrence of numerous pegmatitic dikes cutting the gneiss is proof that the original sediments have been metamorphosed not only by folding, but by igneous intrusion as well. The thoroughly recrystalline character of the gneiss furnishes the final proof of the intensity of the metamorphic changes to which these rocks have been subjected.

*Van Hise, C. R. A Treatise on Metamorphism, Mono 47, U. S. G. S. p. 317
†Van Hise (citd) p. 916.

RESULTS OF DIAMOND DRILLING.

Hole 16 is on the northeast extremity of the maximum magnetic line of the narrow magnetic belt which extends from section 14, T 41 N, R 2 E, to section 24, T 42 N, R 3 E. The rock was tested for a depth of 40 feet. The upper 25 feet of rock in this hole differs so remarkably from that of the lower 15 feet and the rock in both zones is so unique that separate detailed descriptions are demanded.

The rock in the upper 25 feet of the hole is of reddish color, contains abundant dark colored crystals of garnet, is cut by many bands of quartz and is finely banded. The main mass of the rock is composed of dark colored irregular shaped crystals of garnet which are imbedded in a crystalline ground mass of quartz, carbonate, limonite and magnetite. Layers of nearly pure white quartz and of red and white banded chert alternate with the garnet bearing zones. In thin section the rock is observed to be composed of the minerals garnet, quartz, carbonate, limonite and magnetite with a mall amount of biotite and chlorite. The garnets are colorless, irregular in outline, and full of inclusions of other minerals. The carbonate is closely associated with hematite and is probably siderite. This rock is probably an intensely metamorphosed iron formation. This conclusion is warranted from a consideration of its iron content, the occurrence of thin seams or bands of ferruginous chert and its relation to the maximum magnetic line of a linear magnetic belt which has been traced continuously for a distance of 8 miles. Garnetized iron formations are elsewhere found near contacts with intrusive igneous rocks.

The lower 15 feet of core is a feldspathic biotite schist microscopically somewhat similar to that of the upper 25 feet. It differs mainly in the absence of siderite, iron oxide, and the presence of feldspar. It contains abundant small red garnets imbedded in a finely grained, dark, massive ground mass. In thin section the garnets exhibit irregular outlines and lie in an interlocking crystalline mosaic of quartz, biotite and feldspar. The biotite shows a slight tendency toward parallel alignment. With the exception of an incipient sericitic alteration of the feldspar the minerals in the rock show no alteration. The rock is completely recrystalline and no trace of original texture remains. This rock could be derived from a sediment of graywacke type but its essential similarity to the rock in the upper part of this hole, which seems to be without a doubt a metamorphic iron formation, suggests a similar derivation through extreme metamorphism by granitic intrusion, the feldspathic material being a direct contribution from the granite magma. This conclusion is further supported by evidence, in other parts of this range, of the assimilation by granite of the sedimentary rocks, the original positions of which are now occupied by schist and gneisses and are preserved only by linear faint magnetic belts which have been traced continuously in some cases for as much as 20 miles.

Beginning in section 10, T 41 N, R 3 E, a continuous belt of magnetic attraction has been traced in a northeasterly direction a distance of 20 miles to an apparent connection with a magnetic belt of the Turtle range in sections 14 and 15, T 43 N, R 6 E. Three drill holes were put down at widely separated localities on this belt.

Hole 22 was located in section 26, T 42 N, R 4 E, a short distance north of Powell on the C. & N. W. R. R. This hole was sunk on the line of maximum magnetic attraction and, after passing through 122 feet of drift, drilling was continued for a depth of 12 feet in a coarse grained garnetiferous mica schist showing injected veins of granitic material. The rock is composed of quartz, biotite and garnet with considerable chlorite and pyrite, small scattered grains of magnetite, a few needles of rutile and fine flakes of carbonaceous (?) material. This rock is very similar in mineral composition to the kyanite free bands in the kyanitic garnetiferous biotite gneiss that outcrops just north of the magnetic belt two miles west of section 26. It is thoroughly crystalline schist and the only clue to its origin is its present mineral composition. The predominant minerals are biotite and quartz while garnet is occasionally found in considerable abundance. Schists which are composed mainly of quartz and mica are regarded by Van Hise* as probably metamorphic sediments. The general resemblance of this rock to certain layers in the associated kyanite-bearing gneisses is strong presumptive evidence of a sedimentary origin. The intimate injection of granitic material is one, if not the most important, cause of the extreme metamorphism of this rock.

Hole No. 35 in section 2, T 42 N, R 5 E, about 7 miles northeast of hole 22 along the strike of the magnetic belt was put down on the south edge of the magnetic field. The core exhibits dark gray to black, coarsely grained rock heavily impregnated with pyrite and carrying an abundance of small light reddish garnets, for the most part about 1-16 of an inch in diameter. Near the top of the hole are many grains of quartz and pyrite. In thin section the rock is almost identical in texture and composition with the core in the bottom of Hole 33, of the Winegar section of the Turtle range, which is of particular interest in view of the fact that there is an apparent connection between the Turtle and Manitowish ranges along the line of this magnetic belt. The rock is composed of colorless garnets rich in inclusions of fine black particles of carbonaceous material imbedded in a groundmass of interlocking quartz and biotite. Pyrite and small patches of minute

*Van Hise, C. R. Treatise on Metamorphism, Mono. 47, U. S. G. S. p. 916

green fibres similar to those in the core from hole 33 are also present. There can be little doubt of the sedimentary origin of this rock, the best proof of which is the abundant carbonaceous material.

In section 28, T 43 N, R 6 E, about four miles northeast of hole 35, the underlying rocks were tested again by drill hole No. 41. The overburden at this locality extends to a depth of 129 feet and drilling was continued in the ledge for 19 feet. The rock is coarsely grained, garnetiferous biotite-quartz-schist similar to that found in hole 22.

The magnetic belt lying south of the one tested by holes 22, 35 and 41 was tested by three holes. In the vicinity of Powell this belt exhibits two lines of maximum attraction, the southernmost of which is separated from the main belt in section 36, T 42 N, R 4 E, by a short interval of normal territory. Hole 20 (section 26) was sunk on the north line of maximum magnetic variation; hole 24 (section 36, T 42 N, R 4 E) is a short distance north of the maximum line but within the limits of the magnetic field. Seven miles northeast along the strike of the magnetic belt a third drill hole (No. 38) was put down just south of the maximum magnetic variation in section 7, T 42 N, R 6 E.

The rock in hole 20 is coarse grained biotite-muscovite-quartz schist thoroughly impregnated with granitic material. The granite cuts the schist in a series of veins of pegmatite and aplite. In general, the schist is composed of quartz and biotite, with considerable feldspar, pyrite and magnetite. Near the pegmatite veins muscovite is abundantly developed.

Hole 24 penetrated 15 feet of fine grained feldspathic biotite schist cut by veins of pegmatite. The bottom three feet is coarsely grained massive white biotite muscovite granite.

Hole 38 is in feldspathic biotitic quartzose gneiss. A definite banding is produced by alteration of zones of the same apparent mineral composition but of slightly different texture. Occasional narrow pegmatite veins running parallel to the schistosity are to be seen. Like all the other rocks found on this range the gneiss is thoroughly recrystalline and in its present condition contains no direct evidence of its original character.

In the south part of T 42 N, R 5 E, and the north portion of T 41 N, R 5 E, there are four small disconnected areas of magnetic attraction. The two easterly belts have a strike almost at right angles to the strike of the Manitowish ranges.

Hole 32 was put down at the north end of the most easterly belt, which trends a little west of north through section 35, T 42 N, R 5 E. It is just a mile in length and a little less than one-half mile wide. The hole is in the projection of this belt about 300 paces from its northeastern extremity and penetrates coarse grained white muscovite-biotite granite.

GENERAL SUMMARY.

We can briefly sum up the known facts regarding the Manitowish range in three statements, i. e. (1) its position is marked by a series of parallel narrow linear magnetic belts broken here and there by gaps of normal territory; (2) the underlying associated rocks are mainly crystalline schists and gneisses; (3) the schists and gneisses are almost universally associated with large amounts of injected granitic material and pegmatite dikes.

The narrow and linear characters of the magnetic belts admit of but two inferences in regard to the original character of the underlying rocks, viz., they were (1) either folded sedimentaries or (2) basic lavas. At the present time the rocks underlying the magnetic belts are thoroughly crystalline acid schists and gneisses, which fact effectually eliminates the second inference. It is not easy to grasp the significance of such profound metamorphism on such a grand scale. This extreme metamorphism is not confined to the Manitowish range but also occurs throughout the Vieux Desert area, on the western extremity of the Conover slate belt, and doubtless over a large unexplored territory the limits of which can only be conjectured. The original sediments seem to have been permeated, injected, and probably over large territories, absorbed by the intruding granite magma. The rocks now occupying the space originally filled by sediments are crystalline schists which have derived their constituents from both the sediments and the granitic magmas.

CHAPTER VII.

GEOLOGY OF THE VIEUX DESERT DISTRICT.

R. C. ALLEN AND L. P. BARRETT.

The Vieux Desert district includes a belt of country about four to five miles wide and about twenty miles long extending E-W through Lake Vieux Desert across the boundary between Michigan and Wisconsin. (See *Fig. 1*). West of the lake there are two parallel faint magnetic double belts trending E-W across flat sand plains. In Michigan there is a single magnetic belt traversing wooded hilly country from the lake to the middle of T 47 N, R 37 W.

The rocks in the Vieux Desert district in Wisconsin are buried beneath 125 to 200 feet of glacial drift. The thickness of the drift in Michigan is unknown but, as in Wisconsin, there are no rock exposures. Eleven diamond drill holes were sunk in 1912 by the F. I. Carpenter syndicate in the magnetic territory in the vicinity of Lake Vieux Desert and westward. These holes are so located as to give a general idea of the geology of the Vieux Desert district which is essentially similar to that of the Manitowish range. The rocks are mainly coarse grained schists and gneisses, granite and highly metamorphic but recognizable slate and graywacke. A description of the drill cores from each of the eleven holes follows:

Hole 1 is on the north line of maximum magnetic attraction of the northern double belt in the SW¼ SW¼ section 35, T 43 N, R 10 E. The drill penetrated four feet of pink biotite granite.

Hole 2 (SW¼ SW¼ of section 35, T 43 N, R 10 E, Wisconsin) is a short distance north of No. 1. It cut 50 feet of granite and, below it, about 50 feet of dark gray schist cut in many places by pegmatite and granite dikes. The granite is gray and pink, medium grained, and is composed of orthoclase, quartz, microcline, plagioclase, chlorite, biotite, ferrite, muscovite, zircon, apatite, and a few little grains of magnetite-leucoxine. In thin section only a slight tendency toward granulation and the development of mortar structure is to be noted. The orthoclase is full of inclusions of hematite and exhibits considerable alteration to rather large flakes of muscovite. The microcline is fresh and does not appear to be an alteration product of the orthoclase as in the granites of the Wolf Lake area. Plagioclase feldspar is very subordinate and like the microcline is fresh. Biotite is badly altered to chlorite, in many cases the alteration is practically complete. This feature is especially noticeable in the upper 15 feet of core.

The schist from the lower 50 feet of core is fine, even grained and made up principally of quartz, biotite, feldspar, pyrite, graphite and magnetite with occasional grains of epidote and small crystals of apatite. In thin section the feldspar is limpid, unstriated and probably near albite in composition. The content of graphite is a marked feature and gives the rock its dull gray color. Pyrite is very abundant in seams and streaks running parallel to the schistosity. The abundant graphite and pyrite in this rock is strong evidence of its sedimentary origin.

Hole 3 (NW$\frac{1}{4}$ NW$\frac{1}{4}$, section 2, T 42 N, R 10 E, Wisconsin) is about 300 paces north of hole No. 1. The drill penetrated 34 feet of biotitic garnetiferous kyanitic gneiss similar to that on the Manitowish range.

Hole 6 (NE$\frac{1}{4}$ NE$\frac{1}{4}$, section 2, T 42 N, R 10 E, Wisconsin) is about three fourths of a mile east of hole No. 1 and on the same maximum line of magnetic attraction. It is bottomed in light gray banded gneiss composed of quartz, feldspar, pyrite muscovite, biotite and graphite. The banded structure is produced by alternating layers of coarser and finer texture. The coarser and finer textured bands are apparently identical in mineral composition with the exception that the coarser layers are lacking in graphite.

Hole 4 (SW$\frac{1}{4}$ NW$\frac{1}{4}$ section 2, T 42 N, R 10 E, Wisconsin) is a short distance south of the south maximum line of the north belt. It was bottomed at a depth of 206 feet in granite and dark gray, rather fine grained rock made up principally of quartz, garnet and biotite. The granite is coarse grained and pink and appears, in hand specimen, to be composed almost entirely of quartz and feldspar. The gray rock is exceedingly hard and has a well defined schistose structure although in thin section the biotite exhibits a rough parallel alignment. In addition to the minerals mentioned, microscopic examination reveals considerable pyrite and magnetite and a small amount of chlorite, sericite and apatite. The quartz, garnet and biotite are arranged in an allotriomorphic crystalline aggregate. The garnet is filled with inclusions of quartz, pyrite and innumerable particles of magnetite and graphite (?). Some small flakes of sericite are developed along the fractures in the garnet. The larger magnetite crystals are coated with leucoxine. Both pyrite and magnetite are in close association with biotite and as said above are also included in garnet.

Hole 9 (NE$\frac{1}{4}$ NE$\frac{1}{4}$, section 3, T 42 N, R 9 E, Wisconsin) is at the extreme west limit of the north magnetic belt. It is bottomed in granite.

The south magnetic belt was tested by four holes, numbers 5, 7, 10 and 12. These holes were put down at widely spaced localities. In each hole the rock is crystalline coarse grained micaceous schist and gneiss cut by dikes of pegmatite and granite. For the most part the schists are composed of quartz, biotite and muscovite. Garnet and feldspar are locally important. The core from hole 5 is characterized by abundant greenish white talc. Pyrite, magnetite, chlorite, rutile, zircon, and apatite are everywhere present in small quantities.

CONCLUSION.

The rocks of the Vieux Desert district are granite, gneiss, and schist, the gneiss and schist predominating. The gneiss and schist are characterized by the minerals *graphite*, *kyanite*, *garnet*, *magnetite*, and pyrite, and are related to parallel linear symmetrical magnetic belts. It is believed that the schist and gneiss have formed through injection and assimilation of sedimentary rocks by granite magma. The metamorphic effect of granitic intrusion in the Vieux Desert district is apparently similar to that prevalent on the Manitowish range.

CHAPTER VIII.

GEOLOGY OF THE CONOVER DISTRICT.

R. C. ALLEN AND L. P. BARRETT.

The boundaries of the Conover district are ill defined. A series of magnetic belts with a general east-west trend extend through T 41 N, R's 9, 10, 11 and 12 E, Wisconsin, almost exactly parallel to similar magnetic belts in the Vieux Desert district about eight miles north. The geology of the Conover district is known only from exploration by diamond drilling made by the F. I. Carpenter syndicate in 1913. Fifteen holes were drilled with particular reference to the magnetic belts. As a general statement it may be said that the magnetic belts mark the position of a slate series covered by from 150 to 200 feet of glacial drift striking east-west parallel to the magnetic lines. The bedding in the slates is everywhere steeply inclined. As in the Vieux Desert district these slates are intruded by granite by which they are apparently entirely replaced west of the center of T 41 N, R 9 E. From thispoint eastward granite was not encountered under or near the maxmum magnetic lines and the slate shows little or no effect of metamorphism by igneous intrusion. Granite occurs to the south in section 33 and vicinity, T 41 N, R 10 E. A drill hole near the north ¼ corner of section 8 of the same township penetrated slate. This slate is much harder and more highly recrystalline than that which underlies the magnetic belt of the Conover district and probably indicates approach to a contact with the intrusive granite which is known to occur throughout the Vieux Desert district and very probably occupies the greater part of the intervening area.

It is very probable that the slate series of the Conover district is continuous eastward with the slate-iron formation series of the Iron River district. This connection is indicated by the general structural features of the two districts, the similarity of the slates, and the penetration of slate in numerous drill holes in section 4, T 42 N, R 36 W, Michigan, and in a single drill hole in section 9, T 41 N, R 13 E, Wisconsin, thus practically bridging the interval between the eastern extremity of the magnetic belts of the Conover district and slate exposures in the Iron River district. About one and one-quarter miles southwest of the latter locality in the NE¼ of section 17 of the same township another drill hole is in granite.

From the meager information available the Conover slates may be considered as a tongue of the slate-iron formation series of the Iron River district projected westward into the area which has been invaded by the great granite batholith and its outliers of Northern Wisconsin. This granite, as we have seen, terminates the Conover slate belt near the center of T 41 N, R 9 E, Wisconsin, but the main magnetic belt which is underlain by slate throughout the Conover district continues on without break into the granite area for several miles where it is proved by drilling to mark the position of quartz-mica schist and gneiss cut by dykes and stringers of white biotite granite exactly similar to the rocks which underlie the magnetic belt of the Vieux Desert district. There can be no question that this mica schist and gneiss is a metamorphic equivalent of the comparatively unaltered slate underlying the same magnetic belt east of that locality. This relationship is a further evidence of the origin of the mica schists and gneisses of the Vieux Desert district wherein the relationship to the original unaltered sediments is less clear.

The rocks underlying the eastern three-fourths of the Conover district are soft, red, gray, and black slates containing seams of ferruginous chert and carrying abundant iron carbonate. Oxidation has extended to varying depths up to 75 feet and in a couple of drill holes material running as high as 40% metallic iron was encountered on and extending a few feet below the rock surface. It is entirely possible that the Conover slate is associated with productive iron formation which has, however, not been penetrated in drilling.

The Conover slates are exactly similar to those associated with the Vulcan iron formation in the Crystal Falls and Iron River districts.

PETROGRAPHIC DESCRIPTION OF THE CONOVER SLATES.

For the sake of convenience the petrographic description of the rocks penetrated by the various drill holes in the Conover district will be referred to the different magnetic belts wherein these holes are located (see *Fig. 1*).

The most easterly magnetic belt is short, narrow and ill defined. It extends through sections 13, 14 and 15, T 41 N, R 12 E. The rocks underlying this belt have not been explored by drilling.

Belt A extends from section 9, T 41 N. R 12 E, westward three miles into sections 11 and 14, T 41 N, R 11 E. This belt was tested near the south border by hole 48 located near the west ¼ post of section 13, T 41 N, R 11 E. Rock was encountered at 168 feet and drilling was continued to a depth of 65 feet in soft banded ferruginous slate, for the most part red, or grayish red in color but with some gray and greenish gray phases. Banding and cleavage are parallel and steeply inclined to the vertical. No other holes were put down on this belt.

Belt B extends from section 24, T 41 N, R 11 E, 18 miles westward into section 7, T 41 N, R 9 E. It has an average width of about three-quarters of a mile and with the exception of the westernmost five or six miles is characterized by a single continuous maximum magnetic line.

Belt B was tested at several different localities. In the central and eastern part the underlying rock is slate. On the west end where the magnetic field is variable and uneven the slates have suffered extreme metamorphism by the intrusion of granite and are now represented by mica schist. A description of the holes put down on this belt follows:

At the eastern extremity, hole 46, NE$\frac{1}{4}$ of the NE$\frac{1}{4}$, section 23, T 41 N, R 11 E, penetrated ferruginous slate, grading downward into unoxidized greenish gray carbonate slates.

Hole 27, NE$\frac{1}{4}$ of NW$\frac{1}{4}$ section 22, T 41 N, R 10 E, near the south border of the belt, penetrated gray slate. The rock has a good cleavage and a well defined banding. Both structures are parallel and indicate a nearly vertical dip.

In the eastern part of sections 17 and 20, T 41 N, R 10 E, Belt B has two lines of maximum attraction and is also characterized by strong disturbance of the needle. The belt was cross-sectioned at this locality by three drill holes. Hole 8, NE$\frac{1}{4}$ of NE$\frac{1}{4}$, section 20, is located on the south line of maximum magnetic attraction. The rock in this hole, which was tested for a depth of 25 feet, is not duplicated elsewhere in the Conover area and presents some features of exceptional petrographic interest.

The lower ten feet is a soft light grayish green rock composed essentially of carbonate, talc and magnetite. Carbonate forms the body of the rock. Magnetite occurs in disseminated grains although there is a tendency for this mineral to be concentrated in irregular and also roughly rectangular areas. Talc occurs abundantly in irregular masses, thin veins and scattered flakes. This rock has probably resulted from the metamorphism of a dolomite containing a large amount of iron carbonate. Heat and pressure has converted the iron carbonate to magnetite and the dolomite to talc. It is probable that the metamorphism is due to igneous intrusion rather than to deep burial because the rock is not schistose. The igneous intrusives furnished the silica necessary for the formation of talc.

The core from the upper part of the hole exhibits a massive grayish green rock very similar microscopically to that in the lower ten feet. It differs mineralogically in being composed mainly of serpentine with subordinate magnetite and carbonate. The appearance of this rock under the microscope is illustrated in Plate XII. In ordinary light a well defined granular texture is apparent in the arrangement of the magnetite and carbonate but under crossed nicols this texture is obscured by the doubly refracting lattice work of interlocking fibres of serpentine. The serpentine is colorless and has a low birefringence and index of refraction. It is probably the variety antigorite. The carbonate and magnetite are closely associated and their peculiar distribution is their chief feature of interest. The serpentine fibres are arranged without regard to the granular texture outlined by the magnetite and carbonate areas.

The origin of the serpentine rock is not entirely clear. Three possibilities are suggested. (1) It may be an altered olivine rock or dunite in the form of a dike cutting the ferruginous dolomite. (2) It may be derived through serpentinization of forsterite developed in the ferruginous dolomite by contact metamorphic action. (3) The serpentine may have been derived directly from the dolomite through the agency of hot solutions coming from adjacent intrusives without the previous formation of olivine minerals.

If the rock was once a dunite no trace of olivine now remains although the arrangement of the magnetite and carbonate is suggestive that they outline the position of original olivine grains. Objections to this theory are the entire absence of minerals or alteration products of minerals common in olivine rocks such as pyroxine, chromite, plagioclase and spinel and the absence of a sharp boundary between the serpentine rock and the altered ferruginous dolomite.

The metamorphism of dolomite accompanied by the formation of the variety of olivine known as forsterite and the subsequent alteration of the forsterite to serpentine is always brought about by igneous intrusion. The changes that take place involve the reduction of dolomite to calcite, the magnesia combining with silica to form forsterite. The silica is doubtless derived from hot solutions emanating from the igneous intrusives. It is possible that the rock was formed in this way. No igneous rocks were encountered in hole 8, but this fact is of little importance in view of the general evidence of igneous intrusives in the vicinity. If forsterite was once present, subsequent alteration to serpentine has been complete and no trace of the mineral now remains.

The third possibility, viz., the direct production of serpentine from the magnesian carbonate without the previous formation of an olivine mineral is, so far as known to the authors, a type of alteration not previously described. On the basis of the limited data obtainable from one drill hole this type of metamorphism can only be suggested as an interesting possibility. The magnesia could be derived from the dolomite and the silica from outside hot solutions coming from igneous sources. The entire absence of any trace of olivine and the lattice work arrangement of the fibres of serpentine rather than their occurrence in a mesh or sieve structure typical of olivine alteration makes this theory worthy of consideration.

Hole 18, SE$\frac{1}{4}$ of SE$\frac{1}{4}$, section 17, is about a quarter of a mile north of No. 8 and a short distance north of the north maximum line of attraction. This hole was inclined 60° to the south and the underlying rock was tested for a depth of 188 feet. The rock is a banded ferruginous slate containing thin seams of chert and lean iron formation, cut in one place by a narrow dike of greenstone. The dominant phase consists of alternate narrow layers of greenish gray and red slate, although in places the rock is entirely red, in others light gray or green, the red bands being absent. A thin section cut from one of the grayish green phases shows carbonate, quartz, green hornblende, and magnetite with subordinate sericite, chlorite, and epidote. The rock is very fine grained and decidedly schistose. Its clastic origin is plainly apparent from the rounded outlines of the larger quartz grains.

Hole 21, NE$\frac{1}{4}$ of SE$\frac{1}{4}$, section 17, is located about 300 paces north of No. 18 and penetrates banded ferruginous slates essentially similar to the rock found in hole 18.

Hole 23, center of section 17, T 41 N, R 10 E. is outside of the magnetic belt and about one-half mile west and 350 paces north of No. 21. Drilling was continued for 100 feet in red and gray banded ferruginous slate interbedded with a black pyritic phase toward the bottom of the hole.

Three quarters of a mile west of the cross section just described the magnetic belt was tested again by two holes, in the NW$\frac{1}{4}$ of NW$\frac{1}{4}$, section 20, T 41 N, R 10 E. No. 15 is on the point of maximum magnetic attraction, while No. 11 is located 175 paces farther south. The rock from *hole 15* is rich ferruginous slate with some ferruginous chert in the upper 47 feet and gray talcose slate in the lower 60 feet. Analysis of the ferruginous slate near the top of the ledge gives Fe.—32% and P. —.028%. *Hole 11* is in gray banded carbonate slate with occasional red or green layers. This slate is very similar to that found in Nos. 18 and 21.

The rocks underlying the belt were again tested in the NW$\frac{1}{4}$ of SE$\frac{1}{4}$, section 24, T 41 N, R 9 E, by *hole 37*, about 100 paces south of the maximum line of magnetic attraction. The slate at this locality is gray with purple bands and mottling near the surface. Small magnetite octahedra and occasional minute garnets are disseminated throughout the core. In the lower part of the hole there is a slight coarsening of the grain coupled with considerable contortion in the bedding planes. While this rock is still slate, it seems, however, to be considerably metamorphosed. It is probably a gradation phase between the unaltered slate to the east and the highly metamorphic crystalline schist west of this locality.

Hole 43, SW$\frac{1}{4}$ of NW$\frac{1}{4}$, section 17, T 41 N, R 9 E, four miles west of No. 37, penetrated mica schist cut by dikes of white biotite granite. This rock is similar to that found on the Manitowish range and in the Vieux Desert area and is undoubtedly the metamorphic equivalent of the slates found in this same magnetic belt a short distance east, the alteration being caused by granitic intrusion. This belt is continuous, but at its western end where the underlying slates have been metamorphosed by the intrusion of granite the magnetic attractions are variable and no single maximum line can be traced.

Hole 40, NW$\frac{1}{4}$ of SW$\frac{1}{4}$, section 9, T 41 N, R 9 E, was put down in non-magnetic territory about one-half mile north of belt B. The test shows biotite schist and granite similar to that found in hole 37.

Belt C extends from section 7, T 41 N, R 11 E, westward five miles through section 9, T 41 N, R 10 E. It is characterized by two and in places three maximum magnetic lines. This belt was tested by hole 34, SW$\frac{1}{4}$ of SE$\frac{1}{4}$, section 11, T 41 N, R 10 E, just south of the maximum line of variation. The drill core is quartzose slate in the upper 15 feet followed by 10 feet of soft green chlorite schist. The chlorite schist contains seams and layers of hematite in the upper portion. In thin section this rock is found to be composed of a schistose aggregate of chlorite and green hornblende, with many clusters of titanium minerals, considerable sericite or talc, a few scattered flakes of hematite, and an occasional grain of epidote and magnetite. It is not possible to determine the exact relationship of the schist to the quartz slate owing to the broken character of the core near the contact. In some ways this contact is suggestive of a fault breccia cemented by iron oxide, but no positive statement is justified.

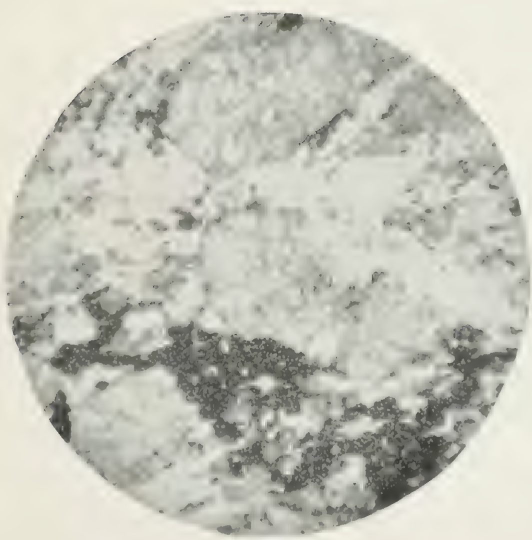
Hole 36, SW$\frac{1}{4}$ of NE$\frac{1}{4}$, section 8, T 41 N, R 10 E, is west of the limits of belt C, and a short distance north of the projected strike. The rock is medium grained garnetiferous biotite schist with stringers and veins of granitic material.

Three holes were put down at other localities in the Conover area not directly connected with belts A, B or C. Hole 31, NE$\frac{1}{4}$ of NE$\frac{1}{4}$, section 33, T 41 N, R 10 E, just north of a small oval shaped magnetic area in the south part of T 41 N, R 10 E, encountered granite. Holes

(A). (Without analizer, X 16). Kyanitic-garnetiferous-gneiss from section 30, T. 42 N., R. 4 E., Wisconsin. This plate is introduced to show the coarse granitoid texture of the kyanite bearing gneiss of the Manitowish range. Kyanite, garnet, quartz, biotite and magnetite are easily recognized.

(B). (Without analizer, X 16). Garnetiferous-pyritic-graphitic rock from drill hole 5 near southeast corner of section 2, T. 42 N., R. 5 E., Wisconsin. This rock is identical with that found in hole 33 of the Winegar section on the Turtle range and is introduced here to show the appearance in thin section of these peculiar garnet rocks which are believed to be altered sediments. The mineral with the high index of refraction is garnet, the large black mass, pyrite, the small black specks, graphite, the light gray flaky mineral, biotite. The white areas are occupied by a coarsely crystalline mosaic of quartz. The garnets are filled with minute black dust not apparent in the reproduction.

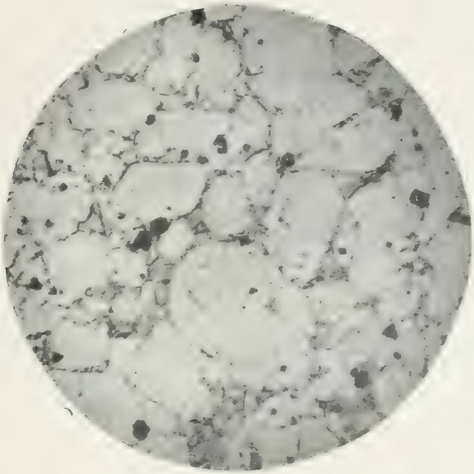
(A)



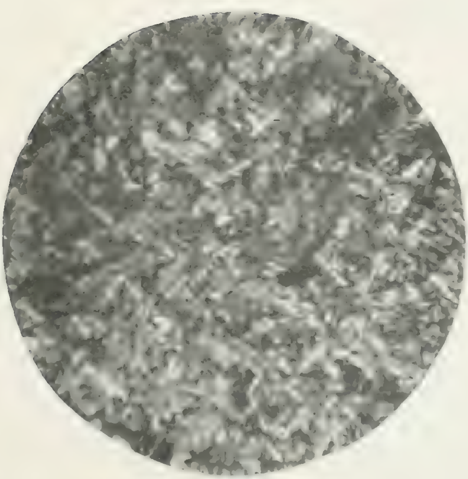
(B)

(A). (Without analizer, X 16). Serpentine-magnetite-carbonate rock from hole 8, NE¼ of NE¼ of section 20, T. 41 N., R. 10 E. The granular texture of the rock as outlined by the arrangement of magnetite and carbonate is well shown. The black areas are magnetite, the gray areas are carbonate, the light areas are colorless serpentine.

(B). (With analizer, X 16). Same as (A) showing obliteration of the granular structure under crossed nicols by the doubly refracting lattice work of serpentine.



(A)



(B)

Nos. 47 and 44, were put down in T 41 N, R 13 E, in non-magnetic territory east of the Conover belts, but in line with their projected trend. Hole 47, SE$\frac{1}{4}$ of NE$\frac{1}{4}$, section 17, is in granite, while hole 44, SW$\frac{1}{4}$ of NW$\frac{1}{4}$, section 9, penetrates about 50 feet of ferruginous slate with occasional chert bands developed toward the botton of the hole. When the hole was abandoned about 2 feet of black slate had been entered.

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CHAPTER IX.

THE PAINT SLATE AND THE WOLF LAKE GRANITE, GNEISS AND SCHIST.

R. C. ALLEN AND L. P. BARRETT.

The Paint slate and the Wolf Lake granite are described together in order to bring out more clearly the evidence pointing to a correlation of the mica schist series of the Turtle range with the great Paint slate formation of the Animikie of the Crystal Falls-Iron River district. The Wolf Lake granite and associated mica schist occupies the territory of about 75 square miles which is enclosed on the north, west, and south sides by the Turtle range and the Watersmeet branch of the Manitowish range. This area opens out eastward into the territory occupied by the Paint slate. There is clear evidence that the Wolf Lake granite is intrusive in the Paint slate. This relation will be discussed following a description of these formations.

THE PAINT SLATE FORMATION.

The Paint slate formation comprises an unknown but undoubtedly great thickness of graywacke, graywacke-slate and gray slate associated with basic intrusive and extrusive igneous rocks occupying a large but ill defined area north and west of the Iron River and Crystal Falls districts, and south of the west end of the Marquette iron range. It constitutes a large part of what has been described as the Michigamme slate series.

The Paint formation is mainly graywacke and graywacke slate and contrasts strongly with the black and gray slate which are associated with the iron formation of the Iron River and Crystal Falls districts and consequently was described by Allen in 1909* under a distinct formation name. Since 1909 these rocks have been further studied by Allen and assistants in T's 44 and 45 N, R's 34, 35, 36 and 37 W, Michigan. In this area exposures are plentiful only in the vicinity of Paint River and its tributaries. A general scarcity of exposures, renders impossible the identification of horizons over any considerable area and makes structural mapping, which is difficult in formations of this type under the most favorable conditions, also impossible. In the

*Publication 3, Michigan Geol. & Biol. Survey eastern part of the area of the Paint slate the rocks are, comparatively speaking, not highly metamorphosed, and are on the whole coarser grained. In many of the exposures bedding structure is preserved but westward and southwestward the rocks become progressively more highly metamorphic until, through recrystallization and the development of schistosity, the bedding structure is wholly obliterated.

The composition of the Paint slate is almost uniform although there are variations ranging from typical graywacke to what may be termed feldspathic quartzite and here and there fine conglomerate. The rocks are everywhere composed dominantly of quartz, orthoclase and plagioclase, evidently derived from older terranes which have broken down by mechanical disintegration. Most of the exposures exhibit a secondary schistose structure which is in some places parallel to the bedding but in most localities intersects the bedding planes at low angles.

Perhaps the most striking characteristic of the series as a whole is the uniform gray or grayish green color of the weathered exposures. The exposures in any one locality are almost exactly similar to those in nearly all other localities with allowance for difference in degree of metamorphism. Another interesting feature is the occurrence of ellipsoidal cavities on the surface of many of the exposures. These cavities are ordinarily 5 or 6 inches long, one or two inches wide and an inch or more deep. The long dimension invariably concides with the strike of the secondary structure. Similar cavities occur in the upper slate formation of the Marenisco range. Another peculiar feature of weathering, particularly well developed in the exposures near the center of the NW$\frac{1}{4}$ of section 15, T 45 N, R 36 W, is the occurrence of small mamillary protuberances from one-half to one inch in diameter projecting a half inch or more above the general surface of the rock. Nearly all of these protuberances have a small hole in the center about a half inch deep. The appearance of the rock reminds one of the surface of boiling mush. The cause of this extraordinary phenomenon is obscure. The rock is typical graywacke. Thin sections cut from the mamillary protuberances exhibit under the microscope no dissimilarity in composition or texture when compared with those cut indiscriminately from the body of the rock.

PETROGRAPHIC DESCRIPTION OF PAINT SLATE.

Microscopic study of the Paint slate affords a basis for division of the series into three main types of rock, viz., (1) graywacke and graywacke schist, (2) fine grained gray slate and (3) mica schist and mica-hornblende schist, the metamorphic equivalents of (1) and (2). Arkose, quartzite and graywacke conglomerate occur here and there but are unimportant in comparison with the enormous mass of the graywacke types.

Graywacke and graywacke schist. The important minerals in these rocks are quartz, orthoclase, plagioclase, chlorite, and sericite. In some specimens biotite and carbonate are abundant. Pyrite, epidote, zoisite, zircon, apatite, tourmaline and magnetite-leucoxine and rarely augite are the accessory minerals.

In general the texture is medium to fine grained and clearly of clastic origin which is manifest in the rounded outlines of the larger grains of quartz and feldspar, while many of the quartz individuals exhibit secondary enlargement. In the schistose graywackes the flakes of chlorite and sericite are in parallel alignment but the grains of quartz and feldspar are not commonly affected by this structure although in some specimens they exhibit a tendency toward orientation of their longer axes in the plane of schistosity. With decrease in the content of feldspar the graywackes grade into arkose and quartzite, and with increase in size of the detrital fragments into conglomerate.

Although quartz is the most abundant mineral, plagioclase, orthoclase, chlorite and sericite are almost equally important. In exceptional cases biotite takes the place of chlorite. The larger grains of plagioclase are fresh and exhibit the characteristic twinning lamellae. The orthoclase commonly shows cloudy alteration and inclusions of hematite particles. The presence of tourmaline in small crystals showing good development in the prism zone but without terminations is practically universal. In some instances the grains are rounded and waterworn and it is probable that the tourmaline is all of detrital origin although this question cannot be determined with certainty. This mineral is never abundant but from one to a half dozen minute crystals are present in every thin section examined. Tourmaline was not re ported by Allen in 1909 but a re-examination of the thin sections of the Paint slate described by him resulted in the identification of this mineral in minute quantity. In some of the slides calcite occurs in isolated areas and less often in irregular individuals arranged in lines parallel to the schistosity. Pyrite and epidote occur in considerable abundance in some of the specimens.

Slate. The slates are gray, grayish green and black. They are essentially similar in mineral composition to the graywackes. The important minerals are quartz, feldspar, chlorite, sericite, biotite and in some instances, carbonaceous material. The minor minerals are pyrite, carbonate, magnetite (usually coated with leucoxine), rutile, apatite, epidote, zircon, and tourmaline. The first two are frequently of considerable importance. The rock is so fine grained and schistose that the mineral composition is only observable under high powers although most of the slides exhibit scattered rounded grains of quartz and feldspar of considerable size and these bear witness to its clastic origin.

Mica schist, hornblende schist and altered graywacke. For the most part these rocks are fine grained feldspathic mica schists which are here and there hornblendic. They are characteristic of the Paint slate in the western part of the area. They are composed of quartz, feldspar, biotite or hornblende, chlorite, sericite, epidote, pyrite, tourma line, zircon, magnetite-leucoxine and apatite.

There are all possible gradations between the mica schists in which the clastic structures and textures have been obliterated by recrystallization and the graywacke and slate. In some of the outcrops the schist alternates with massive or coarser grained layers in which sedimentary textures are still preserved. In other instances microscopic study shows that the recrystallization is only complete for the finer grained material in the rock, the larger fragments retaining their rounded outlines. Some of the schists are also marked by a banding which cuts the plane of schistosity at a small angle. In certain of the less altered varieties the biotite is oriented haphazardly but the schistose structure is retained through the parallel arrangement of chlorite and sericite. The biotite individuals enclose fragments of quartz and feldspar and are plainly secondary.

SUMMARY STATEMENT.

The Paint slate, so far as it is possible to judge from the field observations and microscopic study, comprises a vast thickness of fragmental rocks laid down under subaqueous conditions. The material is apparently derived from the mechanical disintegration of crystalline rocks of acid or intermediate composition. In some localities, particularly along the south border, there are associated greenstones both intrusive and extrusive, but throughout the greater part of the area underlain by the Paint formation greenstone or other igneous rocks are notably absent. Here and there dykes of diabase cut the slate but they are not of great size or of frequent occurrence.

The rocks are characterized by a regional schistosity striking nearly east and west. Both northern and southern dips occur, the latter being characteristic of the more westerly exposures. Where bedding is recognizable it is generally in approximate parallelism to the secondary structures of cleavage or schistosity. It is clear that the rocks have been highly folded by forces acting mainly in a north-south direction.

The relationship of the Paint slate with adjacent formations is not known. It is believed to be conformably above the Middle Huronian

(Animikie) slate-iron formation series of the Crystal Falls and Iron River districts. It is intruded by the Wolf Lake granite which is correlated with the Presque Isle granite of the Gogebic range. The age of the Paint slate is believed to be largely Middle Huronian (Animikie) and is discussed in connection with the general correlations in chapter 2. Part of it may be of Upper Huronian age.

GRANITES, GNEISSES AND SCHISTS OF THE WOLF LAKE AREA.

The exposures in this area comprise a complex of mica schist, green schist, granite and gneiss. The prevailing strike of schistosity is about east and west with dip vertical or steeply inclined to the south, although northerly dips are not uncommon.

The mica schists are best developed in T 46 N, R's 39-40 W, and granites and green schists in T 45 N, R 39 W. However, mica schists are locally found in the latter township and granite and green schist are not entirely lacking in the two northern ones. The schists are everywhere intruded by the granite and are therefore regarded as the oldest rocks of the complex.

The Wolf Lake Granite.

The Wolf Lake granite comprises massive and gneissose varieties of acid composition and subordinate more basic phases including quartz-diorite and syenite. The rocks are mainly white, gray, and pink, with typical granitic, pegmatitic and porphyritic textures.

The primary minerals of the common normal granite are orthoclase, quartz, plagioclase, biotite. fine particles of red hematite, magnetite (often associated with leucoxine) and occasional crystals of zircon and apatite. Secondary minerals are microcline and other feldspars, sericite, chlorite and quartz. Most of the specimens exhibit in thin section a characteristic mortar structure. In the gneissose varieties the biotite and chlorite show parallel orientation. The feldspar, with the exception of microcline, shows considerable alteration. The microcline appears in many cases to be an alteration product of orthoclase. It occurs in small scattered patches in orthoclase crystals, less commonly it forms a border around orthoclase individuals. In some specimens chlorite is the only ferro-magnesian mineral but in others it is closely associated with biotite from which it is probably derived. Hornblende does not occur in the typical normal granite.

The syenite differs from the normal granite only in the almost total absence of quartz and merits no special description.

The more basic varieties of the granite are composed of plagioclase, orthoclase, quartz, biotite, hornblende, magnetite, and titanite. Secondary minerals are feldspar, carbonate, zoisite, epidote and biotite. In thin section the mortar structure is typically developed, the feldspar is commonly granulated, and the mica shows parallel orientation. The feldspar is predominantly plagioclase, generally highly altered to calcite, zoisite, quartz and biotite. Orthoclase is subordinate, shows alteration to sericite and, to some extent, intergrowth with quartz. The rocks have a composition probably very near that of the quartz-diorite.

In certain places small masses of basic material, characterized by the development of considerable hornblende, have separated from the granitic magma.

The Wolf Lake Schists.

The mica schist series includes biotite-quartz schist, biotite-muscovite-garnet schist, hornblende-biotite schist, feldspathic biotite schist and chlorite schist. The greenschist may be more correctly termed amphibolite or hornblendite. Green hornblende is the most abundant and important mineral, especially in the coarse grained varieties and occurs largely to the practical exclusion of other minerals. Part of the green schist appears to be merely a differentiation product of the granitic magma. On the other hand, granite is found plainly intrusive in hornblende schist, and this is probably their prevailing relationship.

Green schist. The green schist or amphibolite is most abundant in the northwest portion of T 45 N, R 39 W. It is uniformly dark green to black and comprises both coarse grained types and fine grained rocks approaching slate in appearance. Under the microscope the coarser grained varieties appear to be made almost entirely of large individuals of green hornblende with a small amount of epidote, quartz and magnetite, the latter closely associated with leucoxine or other titanium minerals. The hornblende is of the strong pleochroic greenish blue variety and commonly shows yellowish limonitic colored bands around the edges and filling the cleavage cracks. The other minerals occur both as inclusions within and in the interstices between the hornblende individuals. Magnetite occurs in irregular grains and clusters of grains closely associated with leucoxine or small crystals of rutile and brookite. In one observation the latter mineral is present in fairly large sized grains some of which show in convergent light beautiful biaxial interference figures.

The finer grained green schists are characterized by a greater abundance of quartz, epidote, carbonate, and secondary feldspar (limpid albite). There is no direct clue to the original character of the green schists but it is probable that they are mashed igneous rocks of basic composition.

Mica schist. Throughout the Wolf Lake area there are exposures of *acid mica schists* similar in many respects to those found in the southern Archean (?) area described in connection with the Marenisco range. The mica schist series is particularly well developed in sections 29, 30, 21 and 32, T 46 N, R 39 W; in section 6, T 45 N, R 39 W; and in the southeastern part of T 46 N, R 40 W. The mica schists are characterized by an abundance of quartz veins, blebs, and stringers parallel to the schistosity. Banded structures at variance with the schistosity were not observed in the Wolf Lake area. In general appearance, however, the mica schists are very similar to those of the Marenisco range and, with the exception of their greater abundance of garnet, mineralogical differences are revealed only under the microscope. Both rocks are generally gray, fine grained and markedly schistose although in both areas there are exceptional non-schistose and massive types which have the appearance of fine grained graywacke.

Under the microscope the Wolf Lake schists reveal the presence of quartz, biotite, muscovite, chlorite, secondary limpid albite, garnet, sericite, magnetite (usually coated with leucoxine), pyrite and hematite. Green hornblende, epidote and calcite are sparingly present. In general the minerals are arranged in a rather fine grained interlocking crystalline mosaic. By extreme mashing the grains of quartz and secondary feldspar are elongated parallel to the orientation of the micas, but as a rule the latter only, show marked alignment. The garnets in all cases were evidently developed under conditions of static metamorphism. They are full of inclusions of other minerals and as a rule have made space for themselves largely by pushing the mica aside, thus developing a more or less perfect augen structure.

The predominant type of mica schist is composed mainly of quartz, pale brown biotite with pale green chlorite, and a lesser amount of colorless muscovite, limpid feldspar and small colorless garnets. Accessory minerals are magnetite and an occasional irregular patch of pyrite generally associated with hematite. In thin section the minerals are arranged in a typical crystalline interlocking mosaic, and while many of the quartz grains show roundish outlines they fit perfectly into the mosaic and in no case have undoubted detrital grains been observed. The very subordinate amount of secondary feldspar is in rather sharp contrast to its abundance in the feldspathic biotite schists of the Southern Archean (?) area of the Marenisco range.

In addition to the rocks described above, certain restricted types are composed of biotite, chlorite, quartz and garnet with pyrite and magnetite-leucoxine as accessories. Other types contain muscovite, biotite, and garnet in large individuals, the mica showing perfect parallel orientation, and in one observation the schist is composed almost entirely of chlorite and quartz with subordinate carbonaceous (?) material.

Through the assistance of Dr. C. K. Leith a composite sample of the mica schist of the Marenisco and Turtle ranges was analyzed both chemically and physically in the hope of making definite determination of its origin. Unfortunately neither analysis offers conclusive evidence. Prof. W. J. Mead of the University of Wisconsin made a solution separation of the crushed sample and examined the heavy residual minerals under the microscope. He found no evidence of rounded grains and to this extent the evidence, though inconclusive, is against sedimentary origin. The chemical analysis was made by Dr. W. G. Wilcox, and is given below:

Analysis of Mica Schist.

SiO_2	59.50%	
Al_2O_3	16.47	(does not include TiO_2)
Fe_2O_3	4.08	
FeO	6.61	
TiO_2	.88	
MnO	Present but not determined.	
CaO	1.04	
MgO	1.59	
Na_2O	2.65	
K_2O	2.40	
CO_2	trace	
Carbon (organic matter)	.35	
Water below 100 deg. C	.12	
Water above 100 deg. C	2.43	
Total	98.02%	

RELATIONS OF WOLF LAKE GRANITE AND MICA SCHIST TO THE PAINT SLATE FORMATION.

We have shown that there is considerable evidence of sedimentary origin of the mica schist of the Southern Archean (?) area of the Marenisco range. (Chapter 4). That the Wolf Lake schists are of sedimentary origin is strongly supported, if not indeed conclusively proven, through what seems to be a direct connection with the Paint Slate in section 13, T 46 N, R 39 W. In the NE$\frac{1}{4}$ of the SW$\frac{1}{4}$ of this section, adjacent to the railroad, mica schist, identical in every respect to those described above, is inseparable from schistose graywacke. Both rocks occur in the same exposures and grade one into the other. There is no question whatever that the mica schist here is an extremely schistose graywacke. The same relations are exhibited about three quarters of a mile southeast of this locality, at and near the rapids on the Middle branch of the Ontonagon river in the SE$\frac{1}{4}$ of section 18, T 46 N, R 38 W. In a distance of about 250 paces the river falls northward in a series of cascades from 50 to 60 feet directly across the E-W strike of the schistosity of the graywacke. The dip of the plane of schistosity is south about 70°, opposed to the direction of the flow of the stream. The rocks exhibit every gradation from dark massive graywacke to crystalline mica schists carrying blebs and stringers of quartz which are exactly similar to the Wolf Lake schists. The graywacke is identical with the most common phases of the Paint slate which apparently underlies the area from this locality eastward to the northern part of the Iron River district. The conclusion that the Paint slate and the mica schist of the Wolf Lake area are one and the same formation is almost inescapable. If this conclusion be embraced it follows that the Paint slate is intruded by the Wolf Lake granite. In chapter 2 on general correlations it is shown that the Paint slate is probably of Middle Huronian age. The age of the Wolf Lake granite is probably not older than Middle Huronian (Animikie). It has been shown in chapters 3, 4, 5, 6 and 7 that the intrusive granite of the east end of the Gogebic range and the Marenisco, Turtle, Manitowish and Vieux Desert-Conover districts is doubtless Middle Huronian (Animikie) and in chapter 2 these granites are correlated with those of the Florence and Menominee ranges which also intrude Animikie sediments. Therefore, it is the most reasonable assumption that the Wolf Lake granite is merely an outlier of the great Animikie granite batholith of Northern Wisconsin, and is of late Middle Huronian age. For a further discussion of the correlation of the Paint slate and the granites which intrude the Animikie sediments see chapter 2.

CHAPTER X.

CORRELATION AND STRUCTURE OF THE PRE-CAMBRIAN FORMATIONS OF THE GWINN IRON-BEARING DISTRICT OF MICHIGAN*

R. C. ALLEN.

Published information regarding the geology of the Gwinn district is very meager. In 1873, Major J. B. Brooks published† a brief description of the locality now occupied by the Princeton and Stegmiller mines, then known as the S. C. Smith mine, in sections 17, 18, and 20, T. 45, R. 25. In speaking of the occurrence of iron ore there he says: "The geographical position is less remarkable than what might be called its geological isolation, for it appears to be in a small patch of Huronian rocks, in the midst of a great area of barren territory, underlain by the Laurentian and Silurian systems." Brooks observed the black slate adjacent to the ore on the northeast in sections 17 and 18 and in "section 20, west of the river, a talcky schist, holding grains of quartz," but was unable to determine the stratigraphic relation of these rocks to the iron formation.

About ten years later this locality was again examined by Dr. Carl Rominger, ‡who writes as follows: "The Cheshire mine, formerly known as the S. C. Smith mine . . . . is working a strip of slaty and quartzose rock beds, known to extend along the valley of the Escanaba River for a distance of nine miles from the northwest corner of section 19, T. 46, R. 26, to the center of T. 45, R. 25." Rominger describes the rocks shown in the mining pits in sections 18 and 20, T. 45, R. 25, in considerable detail. He recognizes an iron formation underlain and overlain by slate. Owing to his misunderstanding of the structure his succession is reversed.

In 1911 the United States Geological Survey published a brief account of the geology of the Gwinn (Swanzy) district by C. R. Van Hise and C. K. Leith.§ These authors had made no detailed survey of this district and attempted merely a summary of the information from other sources available to them at the time their monograph was written. They describe the Gwinn district as a southeastward-pitching syncli-

*Published in the Journal of Geology, Vol. XXII, No. 6, September-October, 1914
†Michigan Geological Survey, I, 150-51.
‡Ibid, V, (1894), Part I, pp. 70-73.
§C. R. Van Hise and C. K. Leith, Monograph 52, U. S. Geological Survey, pp. 283-86.

norium about two miles long and from one-half to two miles wide, the structure being unknown toward the southeast because of the deep overburden. They correlate the pre-Cambrian sedimentary rocks with the Upper Huronian series and describe them as (1) a basal "quartz slate and quartzite grading down into arkose or decomposed granite" which is overlain by (2) the Michigamme slate carrying the Bijiki iron-bearing formation in "lenses and layers" near its base.

Recent studies by the writer, based on field mapping and an examination of the records of several hundred diamond drill holes, show clearly that the Gwinn district contains *at least two* unconformable series of sedimentary rocks. It seems probable that the upper series, which will be described as the Princeton series, is equivalent to the Upper Huronian of the Marquette district, that the lower series, which will be described as the Gwinn series, is equivalent to the Middle Huronian of the Marquette district, and that the Lower Huronian series, while not present in the Gwinn synclinorium, is represented by certain fragments of quartzite and cherty slate in the conglomerate at the base of the lower or Gwinn series.

Without the information afforded by records of drill holes and other exploratory operations, any statement of the geology of the Gwinn district would probably be misleading and in any event necessarily fragmentary and incomplete. Outcrops are not plentiful except in certain restricted localities and are limited to the north two-fifths of the district. The records of drill holes, carefully compiled by geologists of the Cleveland Cliffs Iron Co. and the Oliver Iron Mining Co., are the main reliance for mapping the formations. Only a few of the drill samples were seen by the writer, but each of the formations is somewhere exposed either in outcrops or in excavations and was studied on the ground. It will be seen on the accompanying map that information is entirely wanting in some parts of the synclinorium and in other parts is insufficient for accurate mapping. Only a few of the many faults, which certainly occur, particularly in the north end of the district, have been mapped and the exact location and character of even those is not apparent.

The lithology of the various formations will be considered only so far as essential to an understanding of the succession and the correlations, but the discussion necessarily will be more in detail than the account published in *Monograph 52*, to which reference has been made.

Preliminary to the statement of the geology, there is given in parallel columns for comparison the succession and correlation of the United States Geological Survey and of the writer.

TABLE I.

Table of Correlations. Marquette and Gwinn Districts

	Marquette District—United States Geological Survey.	Gwinn District—U.S. Geol. Survey, 1911	Gwinn District—Mich. Geol. Survey, 1913
Quarternary system	Pleistocene series—glacial drift	Pleistocene series—glacial deposits	Pleistocene series—glacial deposits
Ordovician system Cambrian system	Unconformity. Upper Cambrian (Potsdam sandstone)	Unconformity Limestone Sandstone	Unconformity Limestone and sandstone
Algonkian system—Keweenawan series	Unconformity Not identified but probably represented by part of intrusives in Upper Huronian	Unconformity	Unconformity Not identified but probably represented by basic dikes which intrude all of the pre-Cambrian formations
Huronian series Upper Huronian	Unconformity Greenstone intrusives and extrusives Michigamme slate (slate and mica schist) locally represented by Clarksburg (volcanic) formation Bijiki schist (iron-bearing) Goodrich quartzite	Unconformity Michigamme slate Bijiki iron-bearing member in lenses and layers near base of Michigamme slate Goodrich quartzite. Quartz slate and quartzite grading down into arkose or recomposed granite	Unconformity Michigamme slate, carrying beds of ferruginous slate and chert, quartzite, and graywacke Conglomerate and graywacke (Goodrich)
Middle Huronian	Unconformity Negaunee formation (iron-bearing) Siamo slate Ajibik quartzite		Unconformity Iron-bearing formation and associated overlying and underlying slate (Negaunee-Siamo) Arkose conglomerate, arkose and quartz-slate conglomerate (Ajibik)

TABLE I.—Continued.

	Marquette District—United States Geological Survey.	Gwinn District—U. S. Geol. Survey, 1911.	Gwinn District—Mich. Geol. Survey, 1913.
Lower Huronian	Unconformity Wewe slate Kona dolomite Mesnard quartzite		
Archean system Laurentian series Keewatin series	Unconformity Granite, syenite, peridotite Palmer gneiss Kitchi schist and Mona schist	Unconformity Granite	Unconformity Granite and greenstone, mainly granite

LOCATION AND TOPOGRAPHY, ETC.

The Gwinn synclinorium occupies an area about six miles long and from one to two miles wide, mainly in T 45 N, R 25 W, but extending a short distance into T 44 N, R 25 W. The trend of the major structure is about N 45° W, or almost exactly parallel to the Republic trough, the southern end of which is 22 miles west and 6 miles north of the north end of the Gwinn fold. Gwinn, the principal village, is 16 miles south of the city of Marquette.

The southeast three-fifths of the Gwinn fold is buried beneath a featureless and almost flat sand plain which extends north and east to the hills of the Marquette range. In the opposite direction the surface is broken and hilly with occasional rock exposures. Granite hills encircle the northwest and north sides of the synclinorium. The district is drained by the Escanaba River, which follows the northeast side of the trough to Gwinn and then turns south across the sand plains. On the plains the water table is within a few feet of the surface and the ore bodies are deeply buried under water-saturated sand and gravel, a condition which is a serious menace to mining operations.

The first shipment of ore was made in 1872 from the Cheshire mine, now known as the Princeton No. 1 pit. About 1902 the Cleveland Cliffs Iron Co. purchased the Princeton (Swanzy, Cheshire) mine and during the time which has since elapsed has extended its holdings by purchase and lease until it now controls all of the known workable ore bodies with the exception of the Stegmiller, which is mined by the American (Oliver) Mining Co. Since the building of the beautiful and principal village of Gwinn by the Cleveland Cliffs Iron Co. the name of the district has been changed by common usage from Swanzy to Gwinn. There are five producing mines in the district. Concrete shafts have been sunk to a number of additional ore bodies but it is not known when these will be equipped for mining operations.

NOTES ON THE STRUCTURE OF THE GWINN SYNCLINORIUM.

The Gwinn synclinorium contains two unconformable series of sedimentary rocks, having a combined thickness of from 800 to 1,000 feet. Outliers of flat-lying Paleozoic (Cambrian or Ordovician) sandstone and limestone occur throughout this area. The pre-Cambrian beds are remnants of formations, originally much more extensive, which have escaped erosion by downfolding or depression in the Archean basement.

The synclinorium is constricted to not more than three-fourths of a mile in width in the vicinity of the NW¼ of section 29, T 45, R 25. North of the constricted portion, the rocks are folded and faulted in a complex manner but south of it the structure is apparently somewhat less complicated.

The southern three-fifths of the synclinorium is a spoon-shaped basin four miles long with a maximum width of about two miles. The deepest part of the fold is adjacent to the northeast limb where the Archean granite is reached in many drill holes at depths of from 1,000 to 1,200 feet (see cross-section III-IV., *Fig. 9*). Drilling along the southwest limb indicates a number of sharp drag folds pitching northwest. The folds on the opposite limb are not so sharp and are apparently simple cross-folds. The most prominent one appears in the SE$\frac{1}{4}$ of section 35. The synclinorium practically terminates against a faulted zone on the southeast. It is not possible to determine from present information the full extent of this zone nor the character of the faulting. The rocks in the faulted area are largely slate, chert, conglomerate, and breccia resembling lithologically the succession in the upper or Princeton series, but the regular succession of formations shown on both limbs of the fold terminates abruptly at the line indicated as a fault on the map. Another cross-fault trends diagonally northesat through section 28, producing a horizontal displacement of not less than 700 or 800 ft. in the NE$\frac{1}{4}$ of section 32 and from 150 to 200 ft. in the N$\frac{1}{2}$ of the NW$\frac{1}{4}$ of section 28. The offset in the latter locality may be explained by folding, but the sharpness of the break in the former locality strongly suggests faulting. In any case, the extension and direction of the fault as indicated on the map is to a considerable degree hypothetical.

Knowledge of the structure of the northeast two-fifths of the Gwinn synclinorium pertains chiefly to the northeast limb. The most conspicuous structural feature of this limb is the broad cross-anticline responsible for the extraordinary surface exposure of the iron formation in the vicinity of the Austin and Stephenson mines, giving rise to two prominent synclines, the northern one carrying the Princeton No. 2 ore body and the southern one the Austin-Stephenson deposit (see cross-section I-II *Fig. 9*). Northward from Princeton No. 2 mine the east limb is overturned and dips at an angle of about 80° to the northeast, about parallel to a faulted contact with black slate extending from somewhere north of the Old Swanzy pit in the SW$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 18 southeast for a distance of probably more than a mile. Where observed in the Swanzy pit and in the Princeton No. 1 pit in the SE$\frac{1}{4}$ of section 18, the dip of the fault plane is northeast about 75° or 80°. Both the iron formation and the adjacent slate are intensely sheared along the zone of faulting. The belt of slates adjacent to the fault on the northeast may be stratigraphically either above or below the iron formation so far as the writer has proof. The upper and the lower slate

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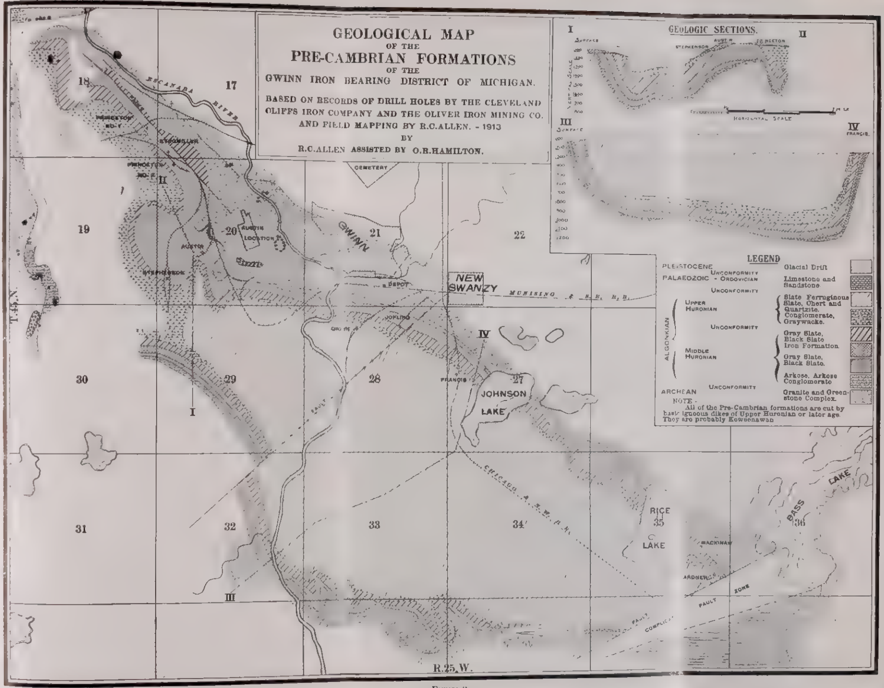

GEOLOGICAL MAP
OF THE
PRE-CAMBRIAN FORMATIONS
OF THE
GWINN IRON BEARING DISTRICT OF MICHIGAN.
BASED ON RECORDS OF DRILL HOLES BY THE CLEVELAND CLIFFS IRON COMPANY AND THE OLIVER IRON MINING CO. AND FIELD MAPPING BY R.C.ALLEN. - 1913
BY
R.C.ALLEN ASSISTED BY O.R.HAMILTON.
GEOLOGIC SECTIONS.
HORIZONTAL SCALE
LEGEND
PLEISTOCENE
UNCONFORMITY
PALAEOZOIC - ORDOVICIAN
UNCONFORMITY
UPPER HURONIAN
UNCONFORMITY
ALGONKIAN
MIDDLE HURONIAN
UNCONFORMITY
ARCHEAN
Glacial Drift
Limestone and Sandstone
Slate Ferruginous Slate, Chert and Quartzite. Conglomerate, Graywacke.
Gray Slate, Black Slate Iron Formation
Gray Slate, Black Slate.
Arkose, Arkose Conglomerate
Granite and Greenstone Complex.
NOTE -
All of the Pre-Cambrian formations are cut by basic igneous dikes of Upper Huronian or later age. They are probably Keweenawan
ESCANABA RIVER
CEMETERY
GWINN
DEPOT
NEW SWANZY
MUNISING & S.E. R.R.
CHICAGO & N.W. R.R.
JOHNSON LAKE
FRANCIS
RICE LAKE
BASS LAKE
MACKINAW
FAULT ZONE
FAULT COMPLEX
T.45.N.
R.25.W.
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I
II
III
IV

Figure 9

members of the Gwinn series are lithologically very similar. Drill holes and the mine workings show that the iron formation in this vicinity lies directly on the basal arkose member of the Gwinn series with here and there a few feet of black slate lying between them. This makes it very probable that the slate belt northeast of the fault belongs to the upper slate member of the Gwinn series. North of the middle of section 18, details of the structure are unknown but the distribution of formations indicated by the few exposures and drill holes suggests deformation by both folding and faulting of a complex character.

ARCHEAN SYSTEM.

The Archean system comprises both acid and basic plutonic rocks, granite greatly predominating. These rocks inclose the synclinorium on the west, north and east sides, encircling the north and northwest sides in bold hills and protruding through the drift in low knobs on the east side from New Swanzy northward. Numerous drill holes reach the system after penetrating the overlying sedimentaries within the borders of the synclinorium.

ALGONKIAN SYSTEM.

The Algonkian system is represented by two unconformable series of Huronian sedimentary rocks, the Princeton (upper) and the Gwinn (lower) series. Both series are intruded by basic dikes, probably of Keweenawan age. The basal conglomerate of the Gwinn series contains pebbles and boulders of quartzite, quartz slate, and siliceous, cherty, slightly dolomitic slate derived from a third sedimentary series unconformably below the Gwinn series but not present so far as known in the Gwinn synclinorium.

MIDDLE HURONIAN.

Gwinn Series.

There are four members of the Gwinn series, viz., from the base upward, (1) conglomerate and arkose, (2) black slate and gray slate, (3) iron formation, and (4) black slate, gray slate, and graywacke.

1. *Conglomerate-arkose*—The basal member of the Gwinn series is mainly arkose and arkose conglomerate. It lies on an uneven surface of Archean granite and is reported to occur in isolated patches over a considerable area outside of the Gwinn synclinorium. Within the fold its thickness varies from practically nothing to above 60 ft. The dominant phase of the member is arkose or decomposed granite. It is evident that the arkose has its origin in the disintegration and subsequent sedimentation of the disintegrated particles of the underlying

granite which in many places it resembles so closely that distinction is difficult. There are phases of the arkose in which the feldspar crystals show little perceptible wear, much less the quartz grains. It is particularly difficult to separate from granite in places near the contact where secondary mica has developed and veins of quartz and pegmatite occur like those in the granite. Phases in which there has been perceptible or conspicuous rounding of the quartz and feldspar particles are commonest and these may be either massive or schistose. The schistosity in the arkose is the result of mashing of the feldspars, by which process the quartz grains are generally not greatly affected. Where the arkose is overlain by the iron formation and particularly by iron ore, as in the mines north and west of Gwinn, it is in many places highly decomposed, soft, and iron stained, the feldspars being largely kaolinized.

The conglomerate is much less abundant than the arkose and according to drill records is not present in most localities. Its occurrence seems to be erratic and, curiously enough, where exposed in the SE$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 19, T. 45, R. 25, it lies some distance above the base of the formation. Drift bowlders of the conglomerate are rather plentiful but the only exposures known to the writer are in the SW$\frac{1}{4}$ of section 19. Here there are 12-15 ft. of it exposed in layers from 1 to 2 ft. thick dipping about 16° E. and striking N. 15° W. At this locality the contact with the granite is about 150 paces west. The matrix of the conglomerate is chiefly arkose but in one exposure it is siliceous, gray slate interbedded with the arkose. The pebbles are up to several inches in diameter and are mainly vein quartz which is abundant in the underlying granite. There are also many fragments of greenschist, dense, vitreous, gray quartzite and siliceous, cherty, slightly dolomitic slate of grayish-green color. The composition of the conglomerate may also be studied to advantage on the waste dump of the Gwinn mine in the NE$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 28 where a bowlder bed was encountered in cutting the pumping station in the shaft. All of the bowlders are well rounded and vary up to 6 to 7 inches in diameter. The matrix is arkose so decomposed that many of the bowlders are lying free on the dump. In addition to the rocks represented in the exposures in section 19 there are many bowlders of granite and greenstone.

The origin of the quartzite and slate pebbles is of great interest in its bearing on the correlation of the Gwinn series. Near Little Lake, about five miles east, in a range of hills on the north side of section 19, T. 45, R. 24, ther are numerous outcrops of quartzite, quartz slate and arkose. Van Hise and Leith considered these rocks to be the base (Goodrich quartzite) of the Gwinn series which we have described. In fact, their description seems to apply mainly to these exposures and not to the basal member of the Gwinn series as it actually exists in the Gwinn synclinorium. There is an arkose and arkose conglomerate in these exposures exactly similar, even to the pebbles in its associated conglomerate, to the basal member of the Gwinn series. This formation, however, is plainly unconformably below the quartzites and quartz slates, as proven by the occurrence of a coarse conglomerate at the base of the quartzite carrying numerous bowlders of the arkose some of which are as much as 2 ft. in diameter. The exposures at Little Lake are not in the Gwinn synclinorium but will be described in a later chapter. The point is emphasized, however, that the presence of quartzite and cherty, quartz-slate pebbles in the basal member of the Gwinn series proves that there is at least one unconformable series of sediments between the Archean and the Gwinn series. The writer believes that this series is the Lower Huronian as represented in the Marquette district a short distance north.

2. *The Lower Slate.*—In the southeastern three-fifths of the district a black, graphitic, and a gray slate formation intervenes between the basal arkose member and the iron formation. It is less generally present from the Stephenson mine northward, in this area never exceeding a few feet in thickness, but south of the Stephenson mine it varies up to above 60 ft. thick. Were it not for lithologic dissimilarity this slate would be included in the basal member, but inasmuch as it represents a distinct change in conditions of sedimentation and moreover seems to maintain a definite stratigraphic relation to the overlying and underlying formations, it should perhaps be described as a distinct member of the series.

3. *The Iron-Bearing Member.*—Like the other formations in the Gwinn series the iron-bearing member varies markedly in thickness but is nevertheless persistent, occupying a constant and definite stratigraphic position in the series. The description of the occurrence of this member in "lenses and layers" in slate by Van Hise and Leith is misleading in so far as this implies that the member is discontinuous within the synclinorium. The thickness of the iron formation is ordinarily 50-100 ft. with a maximum of probably less than 125 ft. and a minimum of only a few feet as shown in some drill holes toward the center of the basin west of the Princeton and Stegmiller mines. Some sections show a greater thickness than 125 ft., which is accounted for by folding. The formation is thinner and at the same time leaner toward the west side of the synclinorium. All of the known ore bodies are on the east limb of the fold.

The iron formation is mainly banded, ferruginous chert similar to the "soft ore jasper" of the other Michigan ranges. The original or unaltered phase is cherty iron carbonate. North of the Swanzy pit in section 18, the base of the formation, as shown by drilling, seems to be mainly grunerite schist. This part of the district shows evidence of greater deformation by folding and faulting than areas farther south.

The upper part of the iron bearing member is slaty in many places and the base of the overlying slate is here and there so ferruginous that it is a matter of choice as to whether it should be mapped as slate or iron formation. On the map these phases are included in the overlying slates.

The iron ores are both Bessemer and non-Bessemer grades, the latter greatly predominating, very soft and fine textured in the main and generally high in moisture. A purplish satin luster is a peculiar characteristic of the Gwinn ores. There are some pits in the upper part of the formation west of the Austin mine that show hard jasper and hard, blue hematite. Localization of the ores is largely coincident with synclinal troughs and faulted zones but is not limited to these structures. An inclined position of the iron formation between the overlying slate and underlying slate or arkose satisfies the structural requirements for ore concentration.

4. *The Upper Slate.*—The upper slate member is from 30 to 100 ft. thick. It is unconformably overlain by the basal conglomerate of the Princeton series. Its relation to the underlying iron-bearing member is largely gradational. It comprises an interbedded series of black slate, gray slate, and dark graywacke-quartzite. The black graphitic phase is more commonly directly above the iron formation than the gray slate, and the graywacke-quartzite phase seems to be in upper and middle horizons.

UPPER HURONIAN.

Princeton Series.

The Princeton series consists of an interbedded series of slates, ferruginous slates, and cherts, quartzites, ferruginous quartzites, and graywacke with a basal conglomerate. The series is 400-500 ft. thick. Probably the entire thickness is not represented in the Gwinn fold. It is rarely seen in outcrops but it has been penetrated by numerous drill holes and some open pits. For the purpose of this article the interesting member is the basal conglomerate.

The basal conglomerate varies from 30 to 50 ft. to more than 100 ft. in thickness. Nearly all of the many drill holes which cross its horizon show its presence but here and there it is represented by a coarse graywacke. So far as known, the only exposures are in the SE$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 18, T. 45, R. 25, where a number of exposures occur on a low brush-covered ridge. Adjacent to them on the east the upper slate member of the Gwinn series is exposed in pits. The strike of the conglomerate is N. 70° W. and the dip 80° N.

The matrix of the conglomerate is coarse, dark graywacke-quartzite, the pebbles are chert and siliceous black slate, quartz, and arkose, derived from the underlying Gwinn series, and quartzite. The matrix carries a good deal of disseminated ferruginous material and some very small fragments of iron ore. There are also a good many small irregular cavities in the rock which are lined with hematite and limonite produced by weathering-out of iron-bearing fragments of some kind. The largest chert fragments are two to three inches long and one-half to an inch wide. All of them show wear by attrition, the smaller ones being generally lens shaped.

So far as can be ascertained, the Princeton and Gwinn series are structurally almost accordant. The strike of the conglomerate where exposed in section 18 indicates discordance in trend with the Gwinn series, but too little is known of the structure in that vicinity to place any importance on this observation.

KEWEENAWAN SERIES (?)

Basic dikes have been cut in a few drill holes and may be observed in section 20, T. 45, R. 25, cutting the basal arkose member of the Gwinn series. These dikes intrude both the Princeton and the Gwinn series. They are older than Paleozoic and younger than the Princeton series. Their age is therefore probably Keweenawan.

PALEOZOIC.

Isolated remnants of limestone and sandstone of Cambrian or Ordovician age, or possibly both, occur throughout the district. Some of these are in excess of 50 ft. thick. No fossils or other means of determining the exact age of these outliers is available at the present time.

CORRELATION OF THE GWINN AND THE PRINCETON SERIES.

It has been shown that the pre-Cambrian sedimentary rocks of the Gwinn synclinorium consist of two unconformable series. The unconformity between them is marked by a basal conglomerate the position, extent, and thickness of which imply an important erosion interval which intervened between the periods of deposition of the two series.

Concerning the respective ages of these two series, it may be said that probably no geologist familiar with the pre-Cambrian formations of the Lake Superior region would correlate the Gwinn (lower) series with the Lower Huronian. It contains an important iron formation associated with graphitic slates, an assemblage of rocks not known in the Lower Huronian. Moreover, the basal conglomerate carries fragments of quartzite and quartz slate dissimilar to any known Archean sediments in Michigan but exactly similar to certain Lower Huronian rocks in the adjacent Marquette district. This evidence considered in connection with the unconformity separating the Princeton and the Gwinn series is a sufficient basis for the correlation suggested, but an additional consideration tending to show that the Gwinn series is Middle Huronian appears in the absence from its basal conglomerate of jasper fragments from the Negaunee formation so strongly developed in the adjacent Marquette district.

Escape from the correlations suggested in this paper involves a disregard or subordination of the importance of the unconformity separating the Gwinn and the Princeton series. There is no certain evidence in this synclinorium of great structural discordance between these two series but it may be and probably is as great as that separating the Upper Huronian and the Middle Huronian series of the Marquette district. Great structural discordance could hardly be expected inasmuch as the main deformation took place after the deposition of the Princeton series. Some structural discordance is implied in the consideration that although the upper slate member of the Gwinn series was probably not cut through in this district, there was sufficient erosion in adjacent territory to uncover the different members of the entire Gwinn series prior to the deposition of the basal conglomerate of the Princeton series.

CHAPTER XI.

EVIDENCE OF THE MIDDLE-UPPER HURONIAN UNCONFORMITY IN THE QUARTZITE HILLS AT LITTLE LAKE, MICHIGAN*

R. C. ALLEN AND L. P. BARRETT.

A critical examination of the exposures of quartzite, quartz slate, and arkose in the hills near Little Lake in T 45 N, R 24 W, Marquette County, Michigan, was inspired by the results of studies by the senior writer in the Gwinn synclinorium, which lies between five and seven miles west.

The Gwinn synclinorium contains two series of Huronian sedimentary rocks, separated by an unconformity which is characterized by a conglomerate at the base of the upper (Princeton) series containing fragments derived from the various formations (including a productive iron-bearing member) of the lower (Gwinn) series and also from a third sedimentary series not represented in the synclinorium. The work at Little Lake resulted in the identification of an unconformity which, in connection with other data to be described, establishes a basis for correlation of the formations at Little Lake with certain of those in the Gwinn synclinorium.

So far as the writers are aware, no previous mapping and careful study of the rocks at Little Lake has been made. Rominger barely mentions the locality in 1894 in the statement that "iron-bearing rock beds occur in the vicinity of Little Lake."† Reference was again made to this locality in 1911 by Van Hise and Leith‡ who correlated the quartzite, quartz slate, and arkose in the hills at Little Lake with the Goodrich quartzite or basal member of the Upper Huronian as developed in the Marquette district and the arkose and arkose conglomerate at the base of the Gwinn series in the adjacent Gwinn (Swanzy) synclinorium.

The succession and correlation of the formations in the Gwinn synclinorium and those at Little Lake are given below:

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*Published in the Journal of Geology Vol. XXII, No. 6, September-October, 1914.

†Michigan Geological Survey, 1894, Vol. V, Part I, p. 71.

‡C. R. Van Hise and C. K. Leith, Monograph 52, U. S. G. S., pp. 283-86.

CORRELATION TABLES.

Gwinn Synclinorium and Little Lake Hills.

	Gwinn-Little Lake Dist., U.S. Geol. Survey, 1911.	Gwinn District, Mich. Geol. Survey, 1913.	Little Lake Hills, Michigan Geol. Survey, 1913.
Quarternary System	Pleistocene Series—Glacial Deposits	Pleistocene Series—Glacial Deposits	Pleistocene Series—Glacial Deposits
Ordovician System? or Cambrian System?	Unconformity Limestone Sandstone	Unconformity Limestone and sandstone	Unconformity Limestone
Algonkian System—Keweenawan Series	Unconformity	Unconformity Not identified by probably represented by basic dikes which intrude all of the pre-Cambrian formations	
Huronian Series Upper Huronian	Michigamme slate Bijiki iron-bearing member in lenses and layers near base of Michigamme slate Goodrich quartzite. Quartz slate and quartzite grading down into arkose or recomposed granite	Michigamme slate, carrying beds of ferruginous slate and chert, quartzite and graywacke Conglomerate and graywacke (Goodrich)	Quartz slate and quartzite Conglomerate
Middle Huronian		Unconformity Iron-bearing formation and associated overlying and underlying slate (Negaunee-Siamo) Arkose conglomerate, arkose and quartz slate conglomerate (Ajibik)	Unconformity Conglomerate, arkose and quartzite.
Lower Huronian			
Archean System Laurentian Series Keewatin Series	Unconformity Granite	Unconformity Granite and greenstone, mainly granite	Not exposed near Little Lake Hills. Probably granite

STRUCTURE OF THE LITTLE LAKE HILLS.

Rising to a height of possibly 100 feet above a featureless flat sand plain near the station of Little Lake are two hills on which there are many exposures of pre-Cambrian arkose, quartzite, and quartz slate with associated conglomerates. These hills present today, in reference to the fluvio-glacial sand plains in which their bases are buried, somewhat the same appearance that they seem to have had near the close of pre-Cambrian time, when they were monadnocks on a pre-Cambrian peneplain, for remnants of flat lying Paleozoic (Cambrian or Ordovician) limestone still cling to their sides and summits.

The eastern and larger hill is nearly a half-mile in diameter: the western and smaller one is about three-eighths of a mile long in an E-W direction with a basal width of about one-eighth of a mile. The exposures are most abundant on the north half of the east hill, but on both hills there are a large number of pits and trenches which were dug many years ago by prospectors whose diligence deserved a better reward than this locality seems to have offered. Aside from the red color of some of the quartz slate beds in the upper series, iron-stained shear zones in the quartzite and arkose, and an exposure at locality *F* (see *Fig. 10*) of about eighteen inches of hematite occupying a lens-shaped cavity along a zone of thrust faulting in massive quartzite, there appears no present evidence of the attractiveness which these hills seem to have presented to the early prospector for iron ore.

The structure of the north side of the east hill is apparently an anticline, the crest of which has been cut away by erosion, thus exposing the arkose and associated conglomerate of the lower (Gwinn) series flanked on the north, east, and west sides by conglomerate, quartzite, and quartz slate of the upper (Princeton) series. This is the only complete structural feature which can be determined from the available data. There is evidence in the development of cleavage and schistose structures, shear zones and faults of both normal and thrust type, that general deformation has been severe. Further evidence of the intensity of deformation is afforded in the overturning of the formations, with consequent apparent reversal in succession, in exposures at locality *A* at the southeast extremity of the east hill. While evidence of minor faulting is abundant in outcrops and pits, it is found impossible with information available to trace the course or measure the throw of any of these faults. The fault at locality *C-H* is a partial exception but the only thing known about this fault is its direction and the fact that its vertical displacement is inconsiderable. In reference to the structure of the west hill perhaps no inferences are warranted. So far as known, the arkose of the lower series is not exposed but the distribution of the lower and higher members of the

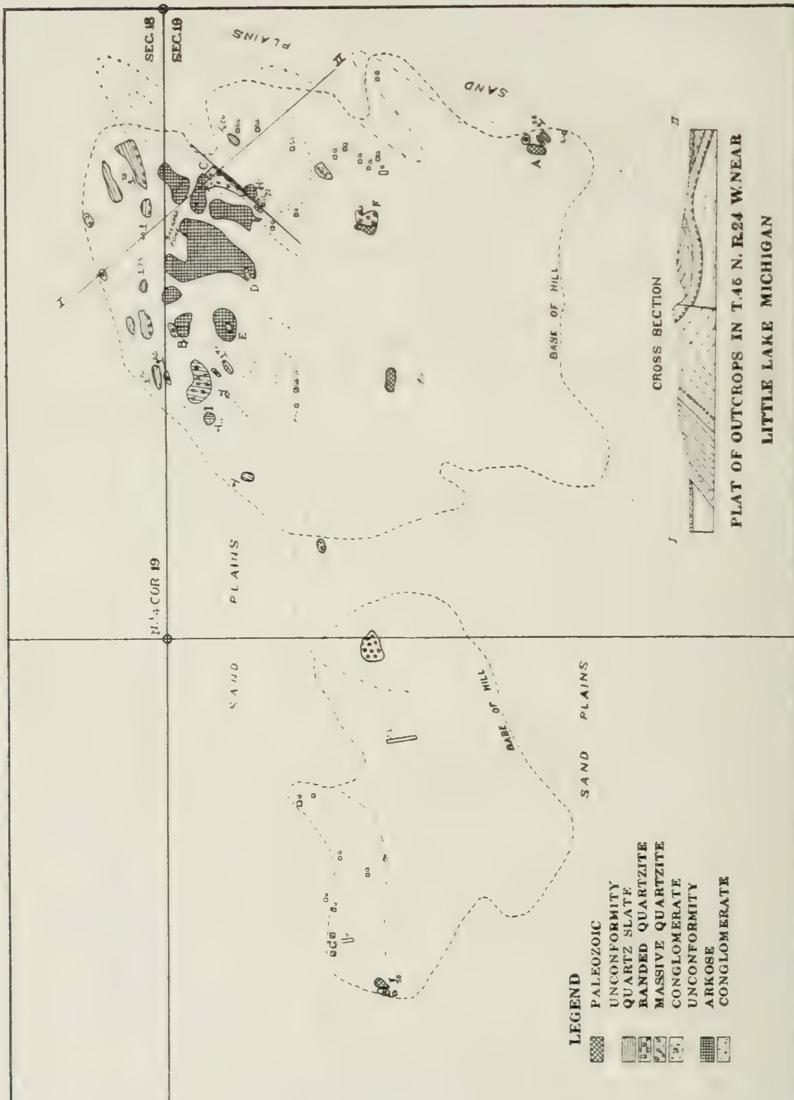
SEC.18
SEC.19
PLAINS
SAND
SAND PLAINS
BASE OF HILL
N.¼ COR 19
SAND PLAINS
BASE OF HILL
SAND PLAINS
CROSS SECTION
PLAT OF OUTCROPS IN T.46 N. R.24 W. NEAR
LITTLE LAKE MICHIGAN
LEGEND
PALEOZOIC
UNCONFORMITY
QUARTZ SLATE
BANDED QUARTZITE
MASSIVE QUARTZITE
CONGLOMERATE
UNCONFORMITY
ARKOSE
CONGLOMERATE

Figure 10.

upper series together with the topographic expression faintly suggests a shallow syncline trending across the hill in a NE-SW direction carrying the quartz slate member in the trough and exposing the underlying quartzite on its opposite flanks. But the structure is probably not so simple as this for there is evidence of faulting in some of the pits.

THE LOWER (GWINN) SERIES.

Arkose and conglomerate.—The major portion of the arkose formation is in reality now an abundantly sericitic quartzite, the sericite being a metamorphic derivative of the original feldspar. The abundance of sericite affords on cleavage surfaces, a characteristic pearly luster. From the dominant phase there are gradations through intermediate phases to typical arkose with feldspar practically unaltered. Of subordinate importance are interstratified lenses of conglomerate varying from a foot or two up to eight feet in thickness. The pebbles are mainly vein quartz well rounded and of various sizes under four inches in diameter. Other pebbles of dense, vitreous, gray quartzite, black chert, and siliceous dolomitic slate are much less abundant. The matrix of the conglomerate beds has the composition of quartzite rather than arkose and is usually dark, dense, vitreous, and slightly sericitic.

Bedding structure is not observable in any of the various phases of the formation, except as it may be represented by an occasional thin layer of gray chert. The deposition of these cherty layers probably heralded the approach of a change in conditions of sedimentation represented by an iron-bearing member in the adjacent Gwinn synclinorium which lies in part directly on a similar arkose-conglomerate formation. At Little Lake the iron-bearing member appears to have been removed by erosion prior to the deposition of the overlying conglomerate and quartzites. The similarity of the arkose-conglomerate of Little Lake to that at the base of the Gwinn series extends to the pebble content. Rounded fragments of dolomitic siliceous slate, and gray quartzite are common to both localities, but the bowlders of granite and green schist which occur in the conglomerate of the Gwinn district were not observed in the exposures at Little Lake.

THE UPPER (PRINCETON) SERIES.

The upper series, so far as represented at Little Lake, comprises a higher horizon of red-and-gray-banded quartz slate and slaty quartzite grading down through banded quartzite and massive non-bedded quartzite into a basal conglomerate.

Conglomerate.—The contact of the upper and the lower series is exposed at localities *B* and *C* (see *Fig. 10*). At locality *B* this contact is distinguishable only on careful examination. The base of the upper series on weathered exposures is not conspicuously dissimilar to the underlying arkose except on freshly fractured surfaces which reveal, in contradistinction to the underlying sericitic, quartz-feldspar rock, a dense, hard matrix of quartzite holding pebbles of vein quartz of sizes less than an inch in diameter. At locality *C*, however, all doubt of the unconformable relations of the arkose-conglomerate and the overlying series is dispelled. The change from arkose to dense, black, vitreous quartzite is abrupt at a wavy contact of knife-like sharpness. In addition to the quartz pebbles observed at locality *C* there are pebbles of chert and large bowlders of the underlying arkose above one foot in diameter. The arkose bowlders are much softer than the embedding matrix of quartzite and weather out to form characteristic pit-like depressions. The full thickness of the basal conglomerate is not exposed at locality *C*, but at locality *B* it is apparently only six feet. At *C* only about four feet are observable.

Quartzite and quartz slate.—There are three distinct main phases of this series, viz., (1) a massive phase associated with the basal conglomerate, grading upward into (2) a banded phase which in turn is over-lain rather sharply by (3) beds of gray- and red-banded quartz slate. Although these three phases correspond to definite stratigraphic horizons, considerable difficulty is experienced in correlating the various exposures of the different members of this series. The chief difficulties refer to the relation of the quartzite on the west hill to that exposed on the east hill and to the determination of the stratigraphic position of the two outcrops of quartzite north of the slate at the base of the east hill. The outcrops of gray quartz slate and red-banded quartz slate on the north slope of the west hill are apparently stratigraphically above the exposures of quartzite in outcrops and pits on its northwest and northeast sides. Whether the quartzite at the base of the north slope of the east hill is stratigraphically above the quartz slate or represents the underlying massive quartzite brought up by faulting cannot be determined.

Extended description of the different phases of the quartz rocks in the upper series has little interest for present purposes. The dissimilarities of the different members refer mainly to texture and bedding structures rather than to composition. The red color of certain layers in the quartz slates is caused by the presence of small particles of finely disseminated hematite.

NOTES ON THE CORRELATION.

In chapter 10 the senior writer discussed the importance of the unconformity separating the Princeton (upper) and Gwinn (lower) series in the Gwinn synclinorium and adduced evidence in support of the correlation of these two series with the Upper and the Middle Huronian. The lithologic similarity of the arkose-conglomerate formation at Little Lake to the basal member of the Gwinn series, only a few miles distant, considered in connection with the unconformity separating it from the overlying quartzites and quartz slates is a sufficient basis for extending the arguments for the correlations in the Gwinn district to cover the two unconformable series at Little Lake. The geology of each area accounts for three unconformable series of sedimentary rocks corresponding to the Lower, Middle, and Upper Huronian of the adjacent Marquette district. The upper two series are present while the lower one is represented in both areas by fragments of some of its formations in the base of the middle series.

The absence in the lower series at Little Lake of the slate and iron formation members developed in the Gwinn synclinorium strengthens the evidence of the importance of the erosion interval which intervened between the deposition of the Princeton and Gwinn series. Incidentally it has a practical bearing on the possibilities for success attendant on drilling for iron ore in the immediate vicinity of the Little Lake hills. Some drilling of which the writers have no records, has already been done and we understand that additional drilling has been contemplated by parties who are likewise ignorant of the results of the former explorations.

CHAPTER XII.

RELATIVE TO AN EXTENSION OF THE MENOMINEE IRON RANGE EASTWARD FROM WAUCEDAH TO ESCANABA, MICHIGAN.*

R. C. ALLEN.

The Menominee Iron Range of Michigan, so far as known, includes a folded series of Huronian rocks trending a little south of east from the Menominee River in T. 40, R. 31 to the longitude of the village of Waucedah, Dickinson county, a distance of about 19 miles. The Lower Huronian is represented by a series of thick formations of quartzite (Sturgeon) and dolomite (Randville), the Middle Huronian (?) by cherty quartzite not exceeding 70 feet in thickness, and the Upper Huronian by a vast thickness of slate (Hanbury) overlain by volcanic green schists (Quinnesec) and carrying two productive iron bearing formations in basal horizons. The Huronian series lies unconformably on the Archean Complex.†

The areal distribution of the iron formation is shown on the accompanying figure 11.

It is reported that drilling a short distance west of the Menominee river in Florence county, Wisconsin, failed to locate the iron formation of the southernmost belt in the territory where it may have been expected to occur judging from its structure and strike between the city of Iron Mountain and the river. In the opposite direction the iron formations are overlapped by Cambrain sandstone in the vicinity of Waucedah. East of Waucedah the thickness of the Paleozoic rocks increases, presumably rather regularly, to about 800 feet in the vicinity of Escanaba.

It has been obvious for many years that the Menominee range Huronian series, including the iron formations, extends an unknown distance east of Waucedah beneath the flat lying Paleozoic formations. The magnetism of certain of the Huronian rocks, particularly (but not exclusively) the iron formation, furnishes the only means short of actual drilling or underground exploration by which they may be traced into the Paleozoic territory. Magnetic surveys of a part of the area east of Waucedah have been made by certain mining companies, and

*Published in Economic Geology, Vol. IX, No. 3, April, 1914

†For description of geology of the Menominee iron range see Monograph 52, U. S. G. S. page 328-46.

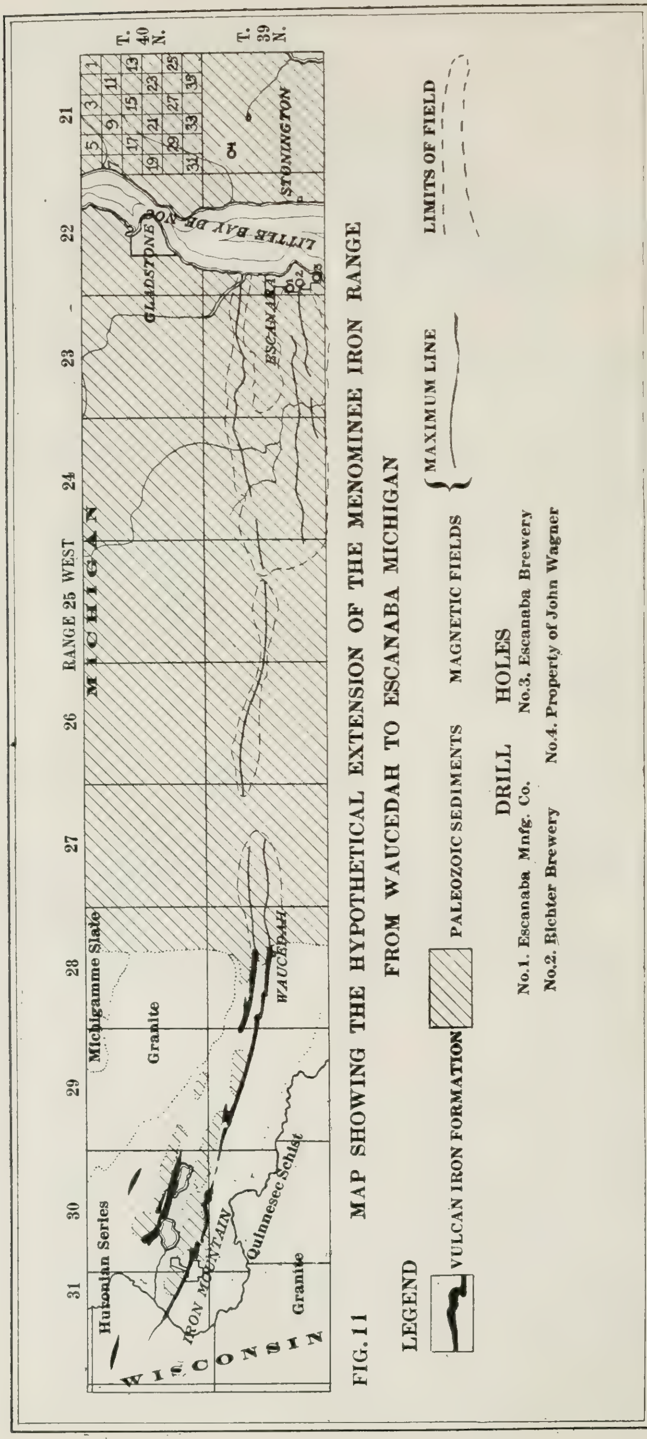
FIG. 11
MAP SHOWING THE HYPOTHETICAL EXTENSION OF THE MENOMINEE IRON RANGE
FROM WAUCEDAH TO ESCANABA MICHIGAN
LEGEND
VULCAN IRON FORMATION
PALEOZOIC SEDIMENTS
MAGNETIC FIELDS
MAXIMUM LINE
LIMITS OF FIELD
DRILL HOLES
No.1. Escanaba Mnfg. Co.
No.2. Richter Brewery
No.3. Escanaba Brewery
No.4. Property of John Wagner
RANGE 25 WEST
31
30
29
28
27
26
24
23
22
21
T. 40 N.
T. 39 N.
MICHIGAN
WISCONSIN
Huronian Series
Michigamme Slate
Granite
IRON MOUNTAIN
Quinnesec Schist
WAUCEDAH
GLADSTONE
LITTLE BAY DE NOC
ESCANABA
STONINGTON

Figure 11.

the results of some of their work were placed at the disposal of the writer. The economic importance and scientific interest of the problem furnished the incentive to complete the magnetic survey of the range eastward to Lake Michigan.

The survey was executed in the field by L. P. Barrett, assisted for a portion of the time by H. J. Allen. Where information was available efforts were extended only to checking the accuracy of former surveys. The results are shown in a general way on the accompanying plate.*

CONCLUSION.

It will be seen that the magnetic belts which are coincident with the two separate belts of iron formation near Waucedah extend eastward without break for about six miles. The assumption that these belts have the same relation to iron formation beneath the Paleozoic rocks that they have to known occurrences at Waucedah and westward seems warranted. It is, however, unsafe to conclude that the magnetic belts further east to Little Bay de Noc are all or even partially underlain by iron formations of the ore bearing type of the Menominee range. From their general and linear-symmetrical characters it may be inferred that the magnetic rocks are folded sedimentaries and that they contain iron, at least partly, in the form of magnetite. But the magnetic beds may or may not be the stratigraphic equivalents of the iron formations of the Menominee range. In this connection the reported extension without break of a magnetic belt from the known iron formation at the opposite end of the range westward into magnetic slates, as shown by drilling, is instructive.

A recent drill hole in the general projection of the northernmost magnetic belt on Stonington Peninsula in the SW¼ of the NW¼ of section 8, T 39 N, R 21 W encountered dense, gray, vitreous quartzite similar to the Sturgeon (Lower Huronian) quartzite of the Menominee range after penetrating 780 feet of Paleozoic beds. It is reported that iron formation was penetrated at a depth of 732 feet at the Escanaba brewery, granite at 810 feet at the Richter brewery, and granite at 931 feet at the plant of the Escanaba Manufacturing Company, all in the city of Escanaba. There is little doubt that the above figures represent in each instance the approximate thickness of the Paleozoic rocks, but inasmuch as no records of the drillings were kept and no samples of the cuttings or cores preserved of the holes in Escanaba little credence should attach to the hearsay reports of the character of the underlying pre-Cambrian rocks.

From the evidence available it may be fairly assumed (1) that the

*Large scale plats showing the magnetic observations may be obtained on application to the state geologist, Lansing, Michigan magnetic belts mark the course of pre-Cambrian sedimentary rocks from Waucedah to Escanaba, (2) that these rocks contain magnetite, (3) that the magnetic beds are probably associated with other sedimentary formations which have little or no magnetism, (4) that it is not improbable that the succession and in a general way the structure of the pre-Cambrian beds may be closely related to those of the Menominee range west of Waucedah, and finally (5) that the occurrence of productive iron formation may be related in some degree and in some place or places between Waucedah and Escanaba to the magnetic belts. In advance of actual drilling operations no further assumptions are warranted.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN.

E. C. CASE AND W. I. ROBINSON.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN.

E. C. CASE AND W. I. ROBINSON.

In southeastern Houghton county, there are three outliers of Paleozoic dolomite called respectively, Big Limestone Mountain, Little Limestone Mountain, and Sherman Hill. Big and Little Limestone Mountains lie half a mile east of the little station of Hazel on the Mass City branch of the Mineral Range Railroad, and directly north of the track. Big Limestone is a ridge a mile long and a half a mile wide running nearly north and south, and terminating in steep walls at its southern end. The western face rises abruptly 300 feet from the surface of the swampy land which surrounds the outliers but the eastern face slopes gently to the swamp level and is covered by a heavy growth of hardwood timber. Little Limestone lies south of Big Limestone and is separated from it by a deep irregular gully partly occupied by swamps and partly filled by glacial debris and talus. This hill is much smaller than Big Limestone. and runs NE-SW in contrast to the north and south trend of Big Limestone. It is also lower, rising but 150 feet from the swamp. The surface has been robbed of its timber by forest fires and the top is now under cultivation. The third and smallest outlier, Sherman Hill, is one and a half miles northeast of Big Limestone. It rises 150 feet above the swamp and is covered by a thick second growth of young hardwood. The dolomite appears as high bare cliffs on the northern and eastern part. All three masses of dolomite lie upon the Jacobsville Sandstone which forms the surface rock of the immediately surrounding country, and can be detected through the masses of talus at intervals along the bases of the hills.

The drift is locally thin around the hills, being mostly sand and gravel with a few scattered boulders. Long tapering slopes of drift extend from the southwestern, lee, sides of Little Limestone and Sherman Hill. The tops of the hills show little drift and no glacial markings were found in the few places where the dolomite appears through the soil and thick vegetation. Northwest of the hills a very heavy drift occurs in the valley of the Little Otter which has cut down through several hundred feet of red clay to the Jacobsville sandstone. The Jacobsville is here darker in color and composed of finer grains than at the outcrops beneath the dolomite of the hills, and as it is considerably lower topographically it is very possibly a lower member.

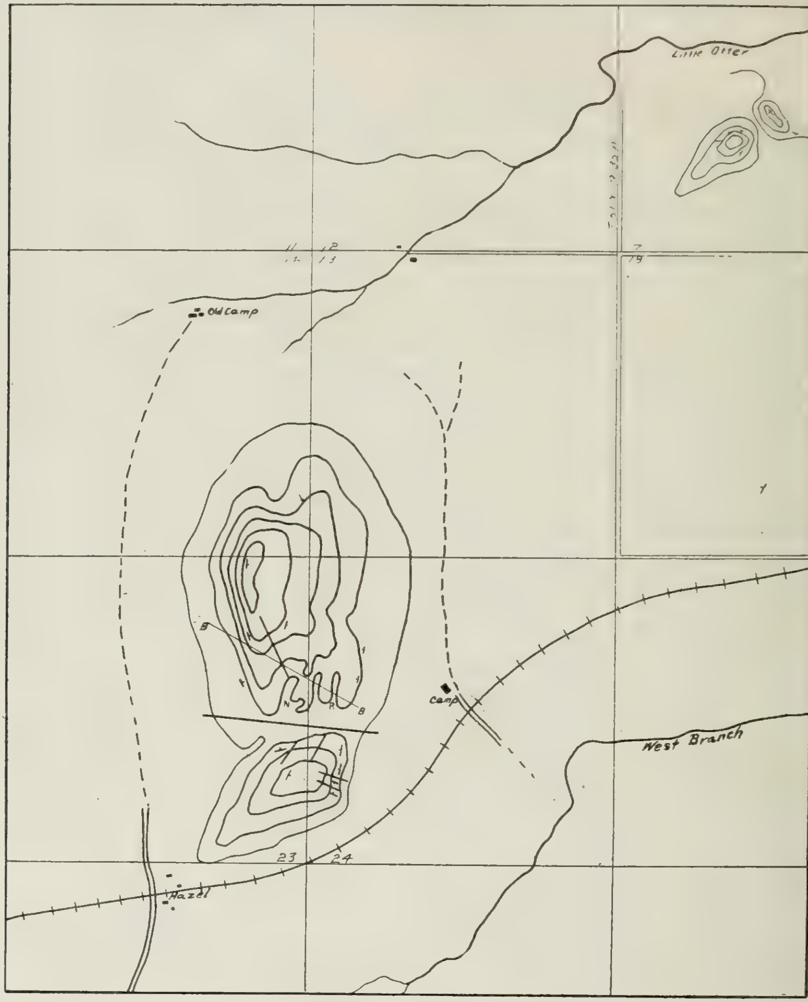

Figure 1. Limestone Mountain and vicinity modified from a map by W. L. Honnold and A. C. Lane. Contour interval 50 feet.

These outliers have been visited by several geologists who have reported variously upon their age and structure. C. T. Jackson*, in 1849, published a report upon the region in which he assigned the sandstone to the Triassic and considered it equivalent to the "New Red" of the Connecticut valley. He regarded it as overlapping the dolomite. He collected *Pentamerus oblongus* and so gave the age of the dolomite as Niagaran. His analysis of the dolomite is as follows:

Calcium Carbonate	44.49
Magnesium carbonate	44.65
Peroxide of Iron	1.98
Silica	8.91
	100.03

Foster and Whitney† in their "Report on the Geology and Topography of the Lake Superior Land District," established the correct position of the dolomite above the sandstone by observing the calcareous nature of the upper layers of the sandstone and the abundant sand grains and silica in the lower layers of the dolomite. They made a considerable collection of fossils which were submitted to James Hall for identification. His conclusion was that "The evidence from the whole together goes to prove that the rocks from which they were obtained belonged to the older Silurian period." The rocks were assigned to the Potsdam and Calciferous sandstones, the Chazy, Birdseye, and Black River limestones, and perhaps Trenton and even Hudson River groups. Hall lists the following fossils,

Maclurea.
Murchisonia or *Loxonema*.
Ambonychia (near *orbiculata* and *amygdalina*).
Modiolopsis (near *truncatus*).
Edmondia (near *subtruncata* and *subangulata*).
Edmondia (near *ventricosa*).
Leptaena sericea.
Orthis sp.
Glyptocrinus (stems).
Orthoceratites.

Dr. Carl Rominger‡ visited the locality and included a description of it in his report on the Upper Peninsula. He noted the very great disturbance, the complex faulting, and the varying dip of the layers

*31st Cong Ex Doc, No. 1, pp. 399 and 452, 1849
†31st Cong Ex. Doc, No. 69, pp. 117-119, 1850
‡Mich Geological Survey, vol. 1, part 3, pp 69-71, 1873

of which he said, " . . . . . it appears to me more probable that there was an underwashing and sinking of the strata during the drift period rather than an actual upheaval of later date." He was essential in agreement with Hall as to the age of the beds and gave the following report on the fossils.

"In the lower ledges, casts of Bivalves and of Gasteropods are numerous, but not well enough preserved for determination; the same is the case with fragments of Orthoceras and Cyrtoceras. I have identified,

Orthis occidentalis.
Orthis testudinaria.
Orthis similar to *pectinella.*
Orthis lynx.
Rhynchonella increbescens.
Leptaena alternata.
Lingula quadrata.
Leptaena sericea.
Pleurotomaria lenticularis.
Subulites similar to *elongatus.*
Murchisonis major.
Bucania.
Ambonychia orbicularis.
Cyrtodonta subtruncata.
Nucula levata? larger than Hall's specimens.
Streptelasma corniculum.

The valve of a Brachiopod similar to the dorsal valve of *Orthis occidentalis*, but with the hinge line extended ear like, and exhibiting an internal septum like the ventral valve of a *Pentamerus*. A specimen of this kind may possibly have induced Jackson to mistake it for *Pentamerus oblongus*."

In 1891 W. L. Honnold, then serving as geologist on the Michigan Geological Survey, spent some time in the vicinity and in connection with his studies made excavations at the base of the hills to determine the nature of the contact of the dolomite with the sandstone. He reported that the dolomite lay in apparently conformable contact with the sandstone which in his opinion forms a gentle syncline. He, also, noted that the upper layers of the sandstone are calcareous and the lower layers of the dolomite siliceous with no transition beds between the two. Unfortunately, Honnold's work has never been published but short abstracts have appeared.*

*Am. Jour. Sci., vol. 42, 3rd. Series, pp. 170-71, 417-19, 1891. Trans. Am. Inst. Min. Eng. vol. 27, pp. 684-85, 1897. Mich. Geol. Surv., Ann. Rep., p. 178, 1903.

In 1909 Lane† gave a further account of Honnold's work and an account of a visit by Hubbard, Seaman and Lane. This report included a map prepared by Honnold and the following list of fossils, which were identified by W. F. Cooper:

Orthoceras vertebrale.
Orthoceras undulostriatum.
Trochonema beloitensis.
Pleurotomaria subconica.
Orthoceras.
Orthoceras (vertebrale) darus.
Cypricardites ventricosus?
Cypricardites ventricosus.
Cypricardites obtusus.
Buthiatrephis.
Cypricardites megambonus.
Cypricardites niota.
Modiolopsis lata.
Cypricardites latus?
Cypricardites glabella.
Cyrtodonta billingsi.
Cypricardites amygdalinus.
Cuneamya subtruncata.
Pentamerus.
Rafinesquina alternata.
Orthis testudinaria.

In the summer of 1913, the authors spent six weeks working upon these outliers in an attempt to finally determine the age and structural relations of the beds. The work has not resulted in as definite conclusions as were hoped for, because the outcrops are largely obscured by heavy talus and a thick growth of vegetation which covers the hills, but it is believed that the information gained is as full as can be obtained in the present condition of the country. The dolomite layers have been much disturbed as is shown by the widely varying dips determined at various points of the outcrops. How this disturbance was caused is still problematical and certain tentative explanations are offered at the close of this paper.

STRATIGRAPHY AND CORRELATION OF THE BEDS.

From our sections and the fossils obtained, the following general section has been made out: (*Fig. 2*). The fossils were determined by

†Mich. Geol. Surv., pub. 6, Geol. Series 4, vol. 2, pp. 523-24, 1909.

GENERALIZED SECTION		
DEVONIAN	Middle	Thickness undetermined
SILURIAN	Niagaran Lockport	Thickness undetermined
ORDOVICIAN	Middle to Upper Richmond	Thickness undetermined
	Upper Part of Lower Richmond Arnheim	Thickness undetermined
	Lower Richmond	10 feet +.
	Upper Galena Stewartville	60 feet. Upper layers fossiliferous
	Decorah Upper Blue	20 feet.
	Upper Black River Upper Bluff	5 feet. at the top fossiliferous 75 feet below barren
CAMBRIAN	Jacobsville	100 feet exposed

Figure 2. The succession of the beds.

the junior author and finally submitted to Dr. E. O. Ulrich of the U. S. Geological Survey for revision and the determination of the exact horizons. For this, and for many helpful suggestions, we desire at this point to express our thanks to Dr. Ulrich.

IX. *Mid-Devonian.*—All that is known of this horizon is a single angular mass of chert, found in the talus on the southeastern slope of Big Limestone. It yielded four fossils:

Chonetes coronatus var.
Productella cf. navicella and spinulicosta.
Spirifer aff. Pennatus.
Cystodictya cf. hamiltonensis.

VIII. *Niagaran.* (Lockport).—A bed of very siliceous material was found on the south slope of Big Limestone (marked N on the map, see *Fig. 1*). It could not be traced a great distance up the slope and it was so badly broken that no satisfactory dip reading could be taken. No trace of such a layer was observed on the tops of any of the hills. The fossils collected are:

Streptelasma spongaxis.
Zaphrentis stokesi.
Duncanella? sp?
Clorinda cf. ventricosa.
Pentamerus sp.
Conchidium decussatum?
Dalmanella cf. elegantula.
Leperditia aff. cylindrica.
Loxonema sp.

VII. *Middle to Upper Richmond.*—Three fossils were found with the Niagaran material, the beds not being distinguishable:

Favosites asper.
Columnaria alveolata.
Plectorthis whitfieldi.

VI. *Upper part of the Lower Richmond.* (Arnheim).—At the locality marked R on the map, a single thin layer of dolomite was found. The rock was almost perpendicular but as it was in the zone of broken talus we cannot be certain that it was in place. The following fossils were found:

Crinoid columnals.
Coeloclema oweni.
Mitoclema minutum.

Mesotrypa patella.
Bythopora striata.
Rhynchotrema perlamellosa.
Rhynchotrema capax.
Conularia formosa.
Primitia cincinnatiensis.
Tedradella persulcata var.
Ceratopsis robusta.
Calymene a new species allied to C. *fayettensis* and C. *mamillatus*, Hall.
Conodont.

V. *Lower Richmond.*—A bed about ten feet thick, containing fossils of this age occurs at the top of Little Limestone and on the southeastern talus slope of Big Limestone. The matrix is a siliceous dolomite and the fossils are as a rule, silicified. The following fossils were collected:

Streptelasma rusticum?
Halysites gracilis.
Inocrinus aff. I. crassus.
Orbiculoidea? (*Schizotreta*) new species.
Rafinesquina new species.
Leptaena unicostata, two new varieties.
Plectambonites sp.
Plectorthis whitfieldi
Plectorthis kankakensis.
Dalmanella aff. rogota.
Dinorthis subquadrata.
Hebertella new species aff. H. insculpta, H. fausta.
Platystrophia sp.
Rhynchotrema capax.

IV. *Galena.* (Stewartville or Upper Galena).′ There is a heavy bedded cream colored dolomite which underlies bed V on Little Limestone, and occurs at the top of Sherman Hill. The fossils were found near the top of the layer which has a thickness of sixty feet. A list of the fossils collected follows:

Cyrtolites cf. retrorsus.
Liospira cf. angustata.
Hormotoma? major.
Lophospira minnesotensis.
Maclurea crassa.
Maclurina manitobensis.
Maclurina cuneata.

Trochonema umbilicatum.
Fusispira subbrevis.
Spiroceras sp.
Salpingostoma cf. expansa Hall, and buelli Whitfield.

III. *Decorah.* (Upper Blue). Below bed IV on the eastern face of Little Limestone there is an old quarry in a thin bedded dolomite. The top layers are gray, the lower layers cream colored with irregular spots of dark red iron stain. The fossils show that the two layers belong at the same horizon. A similar mottled layer carrying Decorah fossils, occurs at Sherman Hill, but here it shades up into the heavy dolomite without the thin bedded layer intervening. The following fossils were found:

Crinoid columnals.
Ceramophylla frondosa.
Trematopora? primigenia.
Halloporina crenulata.
Arthrostylus sp.
Arthoclema sp.
Rhinidictya mutabilis.
Rhinidictya fidelis?
Arthropora simplex.
Escharopora subrecta.
Escharopora confluens.
Streptelasma profundum.
Orthis tricenaria.
Strophomena incurvata.
Strophomena septata.
Dalmanella rogota?
Hormotoma salteri canadensis.
Aparchites sp.

II. *Upper Black River.* (Upper Bluff). At the extreme southwestern part of Big Limestone and eighty feet above the sandstone, there occurs a heavy bedded cream colored fossiliferous dolomite. The beds above and below are completely barren. The following fossils are found.

Ctenodonta nasuta.
Ctenodonta gibberula.
Endodesma? new species.
Cyrtodonta billingsi.
Cyrtodonta cf. billingsi new species.
Cyrtodonta cf. huronensis and subcarinata.

Cyrtodonta tenella.
Cyrtodonta new species.
Vanuxemia aff. niota Hall and subrotunda Ulrich.
Vanuxemia sp.

I. *Potsdam.* (Jacobsville). The lowest members of all the outliers and the only stratum which was observed at all three localities is a dull brown, coarse, poorly cemented sandstone with occasional streaks of a very fine conglomerate or very coarse sandstone. On Big Limestone and Little Limestone the pebbles of the conglomerate layer are of quartz, well rounded, and no larger than a pea. South of Sherman Hill, the conglomerate carries larger pebbles of greenstone and chert. This sandstone has been referred by Lane* to the Jacobsville Sandstone of probably Potsdam age.

STRUCTURE.

The dips in the uppermost of all the exposures show a remarkable diversity although there seems to be quite generally a dip toward the center of the outlier in each case. There is no suggestion of folding. Figure 2 shows the aspect of the southern slope of Big Limestone as seen from Little Limestone. The rocks forming the western face of Big Limestone dip quite regularly eastward. At the south end of the west face a dip of 30° E. 4° N. was obtained. Where the line between sections 14 and 23 crosses the cliff, a dip of 32°, E. 10° N. was found and between these two locations dips easterly were obtained varying from 14° to 20°. From figure 2 it will be seen there is great variation in the dip along the southern face of Big Limestone. The western block dips 20°, N. 60° E., east of this a block dips 14°, N. 51° E., and east of this still another block dips 50°, E. 5° S. Talus covers much

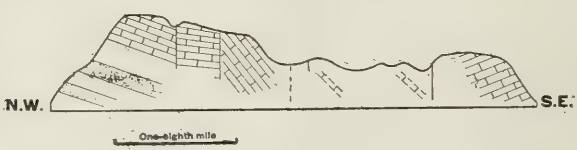

Figure 3. Cross section of southern slope of Big Limestone along B. B. (See map). The white areas indicate talus covered slopes. Vertical scale X 2.

of the remainder of the south cliff but readings were obtained which show that steeply inclined strata occupy the remainder of the section except at the eastern end where a block occurs which dips westerly at various angles. Readings of 21°, 22°, 28°, and 41° were obtained here.

*Jour. Geol., vol. 15, p. 680, 1907.

On Little Limestone a similar irregularity is noticeable. On the northwest cliff a large section of layer IV probably carrying layer V, has slumped away from the main cliff and lies with a dip of 31°, N. 64° E. South of this block on the west face there is a dip of 30°, E. 14° S. Other dips which were noticeable follow:

East face 35°, W. 18° N.
Northeast face 32°, W. 23° N.
Southeast face (Decorah beds) 34°, N. 30° E.

The beds overlying the Decorah and about 20 paces northeast of them 52°, S. 30° W.

These dips, and the dip of the layers of Sherman Hill, are plotted on the map (*Fig. 1*). That the faults which separate these blocks of varying dip are very minor, is proved by the slight displacement of layer IV which can be traced from the east side to the north side of Little Limestone in which distance there are two abrupt changes of dip.

There is evidence however, of a fault of larger importance between Big and Little Limestone. This evidence is mainly in a displacement of the Jacobsville sandstone and is presented in figure 3. From the

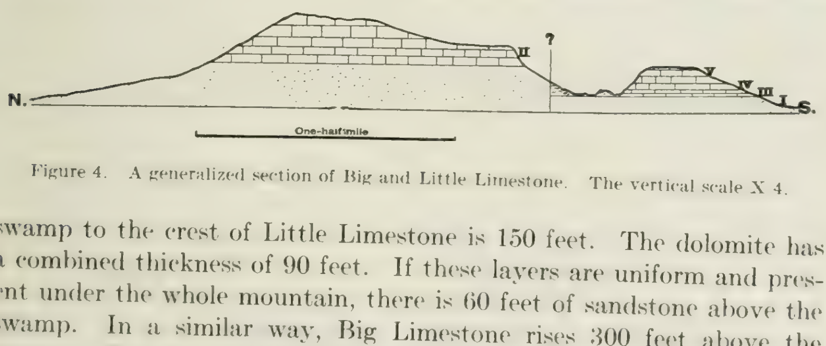

Figure 4. A generalized section of Big and Little Limestone. The vertical scale X 4.

swamp to the crest of Little Limestone is 150 feet. The dolomite has a combined thickness of 90 feet. If these layers are uniform and present under the whole mountain, there is 60 feet of sandstone above the swamp. In a similar way, Big Limestone rises 300 feet above the swamp. The dolomite is 140 feet thick leaving 160 feet of sandstone above the swamp. Allowing 20 feet for change in swamp level there is at least 80 feet difference in level between the sandstone of the two hills. Since these sandstones are lithologically identical, and there is a decided topographic break between them a fault is assumed to be present in the valley.

The succession of beds in Big and Little Limestone mountains, in the few cases in which the beds may be said to be approximately in place, is very different. In Big Limestone layer I, the Jacobsville, is followed by II, the Black River, while at Little Limestone I is followed by III, the Decorah, with not a trace of Black River between. The fossils of the Black River (layer II) were found near the top of Big Limestone, the highest point from which fossils were collected; below them topographically layers V, IV, and III were found apparently in place on Little Limestone (see *Fig. 4*).

From the foregoing account of the stratigraphy it is evident that several new points have been added to the geological history of Northern Michigan. Not only was the region covered by an Ordovician sea but by seas of Silurian and Devonian time as well. Ordovician fossils were discovered by Allen* near Iron River, Michigan and Silurian has been noted by earlier observers at Limestone Mountain, but this is the first time that Devonian fossils have been found in place or near their original position, so far north in the state. Our paleogeographic maps must so far be revised as to extend the Silurian and Devonian seas well into, if not over, the Northern Peninsula. The similarity of the Ordovician fossils with those of Minnesota and Wisconsin shows that the same sea reached from Michigan into these areas. Dr. Ulrich in a letter to the authors cites the peculiarity of the pentameroid forms and their similarity with forms found throughout the extreme western part of North America, indicating a wide connection of the Silurian sea in that direction.

The Devonian material is small in amount but so characteristic that there can be no doubt of the presence of marine waters in Mid-Devonian time. How far the Devonian sea and deposits extended over the Northern Peninsula is impossible to state. Our fossils were obtained from a large fragment on the southeast slope of Big Limestone, involved in the great talus from the lee of the hill, but its size, position, and angular condition, lead us to doubt that it has been transported any great distance, though it may easily have come from some region to the northeast of the dolomite hill. The heavy drift northwest of the mountains also may easily conceal remnants of Paleozoic deposits beyond any hope of detection. We consider it very doubtful that the Devonian deposits were originally connected with the nearest rocks of that age in Canada, in the vicinity of Lake Winnepeg and Hudson Bay.

HISTORY.

We are unable to propose any hypothesis for the preservation of these outliers, so far removed from the deposits with which they were originally connected. That the seas did not endure for any great length of time, is apparent from the relatively thin deposits and it may be that the northern peninsula was a region of limited sedimentation, toward the limits of the invading waters. The upper layers show no peculiar hardness nor consistency which would have enabled them to resist the degrading forces, and, as is shown below, the faulting does not account for the preservation.

*Mich. Geol. and Biol. Surv., Pub. 3, Geol. series 2, pp. 113-16, 1910.

While the hills discussed in this paper are the most remote outcrops of Paleozoic sediments later than the Cambrian known in Michigan, we cannot but believe that more of the same material is buried by the heavy drift to the northwest.

All obtainable evidence shows that the erosional history began, at the earliest, later than Mid-Devonian; how much later cannot be made out but considering the amount of material removed, and the completeness of the removal, we are inclined to the opinion that the region was exposed from sometime late in the Paleozoic.

As the preceding discussion shows, the layers are disturbed by numerous faults in an intricate manner. The fault between Big and Little Limestone is the largest that was detected, with a throw of at least 80 feet, with Big Limestone upthrown. Whether the steep cliff faces of Big and Little Limestone are fault scarps is less certain but this may be possible. The remaining faults are of minor character and importance, and may be accounted for by processes involving only very local conditions.

The fault between Big and Little Limestone.—This is the largest fault observed and throws more light than the others on the history of the hills. As has been shown before, layer II occurs near the top of Big Limestone. It is the lowest stratigraphically and the highest topographically of any fossiliferous bed. On the opposite side of the fault layer III occurs directly upon the sandstone. It is evident that the whole thickness, or nearly so, between the sandstones and layer III is missing on Little Limestone. This may be explained in various ways but because of the lack of evidence, the explanations which are offered are very tentative.

There is no doubt in our minds that the sandstone in the two hills is the same; texture, color, material, peculiarities of cross bedding and included layers of coarser sand grains leave no doubt on this subject. This being true, we must suppose a lack of deposition of layer II on Little Limestone or account for its disappearance by erosion or solution. Under the first hypothesis, that of a lack of deposition on the site of Little Limestone, we would postulate an erosional irregularity of surface which permitted the deposition of a considerable thickness of Ordovician in the position of Big Limestone while the site of Little Limestone was occupied by an elevation not covered until much later by the invading sea. This idea is strengthened by the occurrence of a layer of dolomite, mottled by irregular spots of red, just above the sandstone wherever the sandstone and dolomite were together, irrespective of locality or stratigraphic position. This is seen on Big and Little Limestone, and Sherman Hill. The faulting took place along the edge of the elevation (see *Fig. 5*).

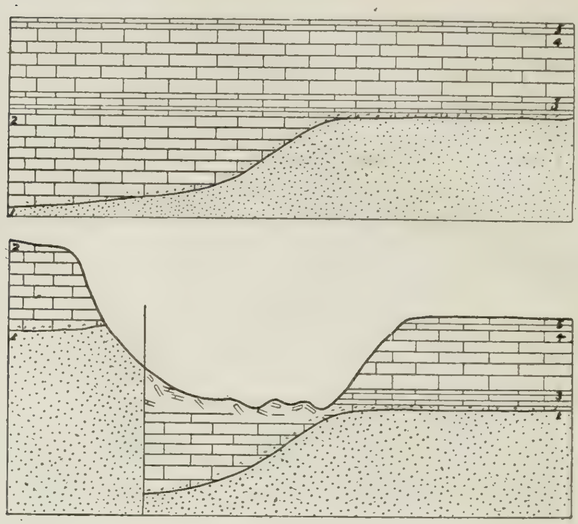

Figure 5. The upper figure shows a hypothetical progressive overlap. The lower figure shows the present condition due to faulting and erosion.

As alternative hypotheses, we may suggest the following: (1) the sandstone may be different in the two hills, that below layer II on Little Limestone being higher stratigraphically than that at the base of Big Limestone. This we regard as an impossibility for reasons given above. (2) The outcrops of layer III on Little Limestone may be large blocks fallen from a higher position because of undercutting and slumping of the layers. That such undercutting and slumping has occured at places on both hills in pre-glacial and glacial times is certain, but to assume it for layer II, ivolves the further assumption that the core of Little Limestone is formed by layer I, at least 80 feet thick, and since the whole hill does not rise over 90 feet from the sandstone, there is not room for such a core. It is very peculiar that no fossils of layer I were found on Little Limestone if any remnant of such a core exists. There is some possibility that Little Limestone has been split by a fault equal in throw, to the fault between Big and Little Limestone and parallel to it, and that the full series is represented on the east end of Little Limestone. One or two points support this suggestion. The east face of the north end of Little Limestone is very steep, descending abruptly to the swamp level. On the south end of the same face the slopes are less steep and there is a slight but well marked terrace indicating the position of the sandstone which outcrops here some distance above swamp level. This assumption of structure while possible is not less complicated than the one of an irregular surface of sandstone upon which the dolomite was deposited, and on the whole seems less satisfactory to us.

Layers VI, VII, VIII and IX are so irregular in position, and so evidently involved in the debris, that we are inclined to believe that they are not in position but attained their present attitude as landslides or slumps due to undercutting by surface or underground waters in comparatively recent times.

In our opinion these outliers have been broken both by major faults, which involve the sandstone below, and by minor faults or breaks, the result of erosional forces. Unfortunately our work does not throw much light upon the age of the great Keweenawan fault, the outliers do not approach near enough to the fault line to afford definite evidence. All that we can say safely is that there were considerable movements later than Mid-Devonian time, involving the Cambrian rocks.

In the preparation of this report the authors have had the advantage of a study of a manuscript "Report on the fossils of Limestone Mountain" prepared by Professor A. C. Lane while he was State Geologist of Michigan.

In conclusion the senior author wishes to state that most of the field work was done by the junior author and that to him is largely due the credit for the discovery of the wide extension of the Paleozoic seas over the Northern Peninsula of Michigan.

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